MEDICAL GUIDE FOR FLYING PERSONNEL

By

HEINZ VON DIRINGSHOFEN

Oberstabsartz der Luftwaffe

1939

Translated by

MAJOR VELYIEN E. HENDERSON

M.A., M.B., C.A.M.C., Retired

Professor of Pharmacology, University of Toronto

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PREFACE

This medical guide for flying personnel is intended to fulfil two purposes.

1. It aims at discussing the important medical problems of the flying service so that the flier obtains a modern scientific knowledge of the medical aspects of flying which he can apply for the maintenance of his health and to increase his flying capabilities.

2. It is further intended to give the physician of the air force the fundamental medical knowledge in regard to aviation so that he may counsel and instruct the flying personnel in the complex medical questions which have to do with the flying service.

In order to fulfil this latter task it has been necessary to discuss certain questions from the aspects of physics and physiology somewhat thoroughly and in part somewhat theoretically. This is particularly true of the physical introduction in the chapter "Action of Acceleration and Centrifugal Force" and its physiological explanation. These passages, which are somewhat difficult for the person without medical knowledge and which are enclosed in square brackets, the flier can leave unread.

TRANSLATOR'S PREFACE

This translation was made for the benefit of the Medical Officers attached to the Air Force, but it has been considered by those who have read it so valuable that it has been printed so that it might be available to all members of the Air Force. The translation reproduces the original text as accurately as possible. The translator wishes to express his gratitude to Lieut.-Col. A. A. James, Principal Medical Officer of No. 1 Training Command R.C.A.F., who has kindly read the entire manuscript and aided with his advice; particularly to Wing Commander D'Arcy Greig, R.A.F., who has been of the greatest assistance in finding the correct English rendering for the flying terms; to Professor E. A. Bott for arranging for the photostatic copy of the book; and to my colleagues Capt. W. R. Franks and Capt. G. E. Hall, C.A.M.C., Professors D. Y. Solandt and J. K. W. Ferguson who have looked over sections of the book and criticized it for me. Certain of the illustrations in the original have been omitted as they were not necessary. Thanks are also due to Mr. A. H. Taylor for redrawing some of the cuts and to Miss D. Caldecott for her care in preparing the manuscript.

Toronto, June, 1940.

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A. INTRODUCTION

In the last few years the rapid development in construction has so increased the performance of aeroplanes in climbing capacity, speed, and turning ability that the limits of human adaptability to the effects of altitude and of acceleration have been reached, and in part exceeded, by attempts to fly these machines at full capacity.

We need only to think of the fact that in the last world height record by a motor driven machine, a height of 17,000 m., 55,700 ft., above sea level was attained and that the ceiling of the new pursuit machines is more than 10,000 m., 32,800 ft.

Without the use of oxygen human capacity for action decreases at 5,000 m., 16,400 ft., and heights over 8,000 m., 26,200 ft., without oxygen may lead in a few minutes to death through oxygen lack.

The world's speed record is now over 700 km., 434 miles per hour, and not less than 500 km., 310 miles per hour, is required today from mass-produced pursuit planes, and this has also been obtained by the faster bombers. At these speeds sharp turns may lead to disturbances of vision and unconsciousness. Fatal accidents are known to have occurred due to the effects of height and of centrifugal force.

These few examples show us distinctly enough that it is no longer sufficient today that a pilot should merely fly well and have mastered the technical flying equipment. He must also know what he himself and his crew can stand physically.

The crew of high flying planes must know where the danger limits of physical endurance lie and by what means they can extend and exceed these limits. Further, the pilot must know what deceptions of sensation may occur during blind flying which may endanger the safety of the flight.

In brief: The flying personnel must know the practically important results of medical flying science, the purpose of which is to prevent accidents arising from the inadequate adaptation of the human body to the abnormal influences which arise in flying, and to increase the human capacities as far as possible beyond what may be regarded as normal.

The absolutely necessary and important knowledge for high flying personnel is set forth in this guide in as condensed and as comprehensible a form as possible. Further it is intended to give the medical officer attached to the flying corps the fundamental knowledge necessary for the medical guidance and the instruction of flying personnel in the medical aspects of flying.

B. HIGH FLIGHTS

1. The Atmospheric Air

(*a*) The Composition of the Atmosphere

The surface of the earth is surrounded by an air mantle whose composition to the height of 12,000 m., 7.4 miles, remains approximately constant (fig. 1). (The latest investigations of the stratosphere show that the mixture of gases in the air even above 12,000 m. changes but slightly.) Oxygen can be shown to exist by spectral analysis of the polar light even at altitudes above 100 km., 62 miles. About 4/5, 78%, of dry air is nitrogen and 21%, about 1/5, is oxygen. In addition, there occur in the air several rare gases, chiefly argon, which are unimportant for human respiration and also water vapour in varying amounts, on an average about 1%. This plays an important role in the maintenance of the warmth of the surface of the earth, as it decreases the radiation of heat from the earth's surface to outer space and forms the source of clouds, mists, rain, snow, and hail.

The cause of the uniform mixture of the air is the currents and whorls, upwards and downwards, produced by the unequal warming of the earth's surface. These upward-directed currents make gliding possible and are in part made visible by the sudden upward streaming of the clouds. Above 12,000 m. in our latitudes these vertical mixing currents become gradually less in the atmosphere and the stratosphere begins. The limits lie lower at the poles and higher at the equator (about 14,000 m., 8.6 miles) owing to the stronger radiation of the sun.

(*b*) The Air Temperature

The temperature, which decreases on an average about 6°C. for each 1,000 m., 3,300 ft., of elevation, remains uniform above the lower limit of the stratosphere and, depending on the time of year, is from −50°C. (−122°F.); because here there is an equilibrium between the incoming and outgoing radiated heat. Above this limit also, according to modern views, the gases begin to form layers in accordance with their specific gravities, so that over the oxygen and nitrogen floats the thirteen times lighter hydrogen which, like the uninflammable helium, we employ for filling balloons.

(*c*) Air Pressure and Density

Although the air at normal density in the neighbourhood of the earth's surface weighs only the 770th part of that of water, nevertheless

the 100 kilometer high gas mantle on the earth presses upon each square centimetre with a force of about 1 kilogramme. The atmospheric pressure is capable of counterbalancing a column of 33 ft. of water or of 760 mm. of mercury, Hg. The air is indeed, due to its weight, increasingly compressed as it approaches the earth and thus

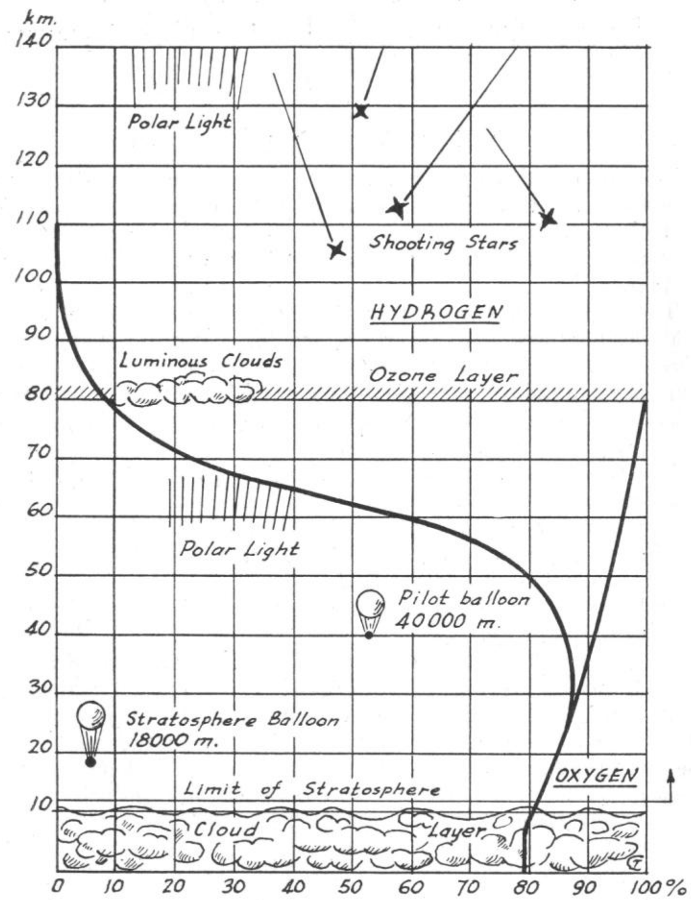

Fig. 1.—The atmosphere. Below 12 km. lies the so-called troposphere, above this the stratosphere. The atmosphere proper fades out at about 100 km., the last layer being largely hydrogen.

the density of the gaseous particles of the air are increased and hence the air density and pressure.

On mounting above sea level the column of air decreases and hence the air density decreases and also the atmospheric pressure (see atmospheric pressure curve, fig. 2).

The atmospheric pressure and the air density are then at

5,000 m., 16,400 ft. only about 1/2
10,000 m., 32,800 ft. only about 1/4
15,000 m., 49,200 ft. only about 1/10
} of the atmospheric pressure at sea level.

(*d*) The Partial Pressure of Oxygen

The pressure that a gas or a mixture of gases exerts on all surfaces is due to the movements produced by heat on the smallest gas particles, the molecules. These molecules collide with the confining surfaces. The sum of the forces of these blows of the molecules constitutes the gas pressure.

The higher the temperature the greater the movement of the molecules produced by the warmth, and consequently the greater the energy produced by the molecular blows. If the number of the gas molecules in a unit of space (i.e., the density) changes, the number of molecular blows changes proportionately if the temperature remains constant.

The pressure of a gas is therefore directly dependent on its temperature and on its density.

In mixtures of gases the molecular blows of the individual gas are summed to give the total pressure. The fraction of the pressure due to an individual gas is its "Partial Pressure."

The purely physical action of a gas mixture is always dependent on the total pressure.

The chemical action and the chemico-physical ability of a single gas in a mixture to combine, for example of the oxygen in the air to combine with the red colouring matter of the blood, is essentially dependent on its partial pressure, i.e. merely on the number and energy of the blows exerted by the oxygen molecules alone on the red blood pigment. The partial pressure of oxygen in a gas is its fraction of the total pressure. It is therefore at atmospheric pressure, 1/5 of the total pressure, i.e. 1/5 of 760 mm. of Mercury = 152 mm. Hg. Pure oxygen, i.e. 100%, has at a height of 12,000 m., 39,300 ft., where the total pressure is only 152 mm. Hg., the same oxygen partial pressure as atmospheric air at sea level, namely 152 mm. (see fig. 2).

Therefore, for an adequate oxygenation of the blood, it is quite unimportant whether the necessary partial pressure of oxygen is

obtained by breathing air which contains only 1/5 of oxygen at normal atmospheric pressure or by breathing pure oxygen when the atmospheric pressure is greatly reduced at high elevations. Also, high altitude sickness arising from a reduction of the total atmospheric pressure can be produced just as well by lowering the oxygen partial pressure as by decreasing the percentage of oxygen contained in an air mixture breathed at a normal pressure.

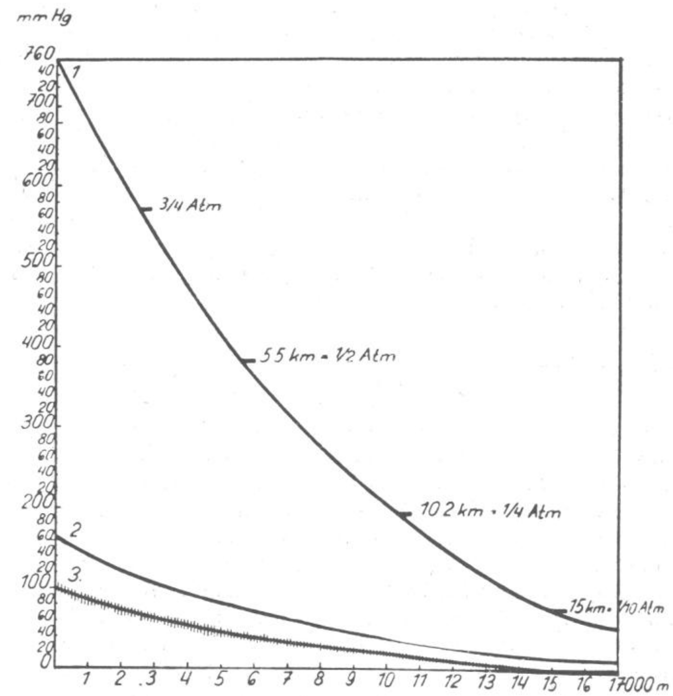

Fig. 2.—*Line 1*—Curve of atmospheric pressure at various heights which are indicated on the base line in kilometres (3 km. = 9800 ft.; 5 = 16.400; 8 = 26.200; and 10 = 32.800). The pressures are shown on the left in mm. Hg. and indicated in fractions of atmospheres (atm.) along the curve.
Line 2—Curve of oxygen partial pressure in the atmosphere.
Line 3—Curve of oxygen partial pressure in the terminal air sacs of the lung.

Therefore, there becomes available for the investigation of altitude sickness either the reduced pressure chamber or the apparatus for reducing the oxygen percentage.

2. The Effect of Reducing the Atmospheric Pressure

When considering the effect of reducing the atmospheric pressure on the human body, the misconception could readily arise that the tissues of the body during a flight to high altitudes must expand due to the decrease in pressure upon the body's surface, or that the blood vessels must produce a higher internal pressure owing to the decrease in the counter-pressure from without. This conclusion is, however, not justified because the tissues of the body contain more than 70% of water and the rest consists of substances which, like a fluid, cannot be markedly compressed even by a pressure of several atmospheres. Therefore a decrease of pressure from one atmosphere to nothing (this would correspond to the bursting of a positive pressure cabin in empty space) would lead to no noticeable expansion of the body tissue or of the blood vessels.

(*a*) The Effect of Reduction of the Atmospheric Pressure on the Gases in the Blood

The effect on the gases contained in the blood is quite different. So far as these gases are dissolved in the blood, the equalization of pressure with the outer air takes place sufficiently rapidly while the blood flows through the lungs, even in the modern pursuit aeroplanes. Nevertheless, a very sudden decrease in atmospheric pressure as by the bursting of a positive pressure cabin, if the person has been breathing atmospheric air with 78% of nitrogen, may lead to the release of bubbles of nitrogen from the blood (like the release of gas bubbles in soda water after it has left its bottle). The gas bubbles may, as in (diver's) caisson sickness, plug up the finest blood vessels. This danger can be greatly reduced by the inhalation of oxygen in the positive pressure cabin, since by the prolonged respiration of pure oxygen the nitrogen is gradually forced out of the blood stream and according to the prevailing views no dangerous gas bubbles could be formed in the blood.

The increase of pressure in coming down in an aeroplane, will lead to the liberated nitrogen bubbles being taken up again by the blood. Therefore the best treatment of "bends" is a rapid descent.

The nitrogen contained in tissue fluids can be released by a very rapid and sufficient decrease in the atmospheric pressure and produce

symptoms. For example, in the cavities of the larger joints, for example in the shoulder or hip, above 8,000 m., 26,200 ft., the gas bubbles may be released and cause violent pain at a normal rate of ascent. These pains disappear at once on reducing the altitude.

(*b*) The Effect of Reduction of Pressure on the Gases in the Intestines and in the Cavities of the Body

Spaces in the body filled with gas or air may cause marked distress, even by relatively slight changes in the external pressure.

The gases in the gut expand (if they cannot be got rid of by natural processes) corresponding to the change in pressure. At 5,500 m., 18,000 ft., they are doubled in volume, at 8,000 m., 26,200 ft., they are quadrupled, and at 15,000 m., 49,200 ft., they expand tenfold. If there is an increased tendency to gas formation, a disagreeable sensation of pressure in the belly may arise even at 5,000 m., 16,400 ft. And in addition by forcing up the diaphragm the adequacy of respiration may be reduced.

Therefore it is advisable to avoid gas-forming articles of diet such as legumes (beans), or if a tendency to distension exists to take before a high flight a half teaspoonful or a tablet of animal charcoal because such charcoal absorbs the gas physically.

Critical conditions may arise in persons with marked gas formation if they are exposed to a sudden reduction in pressure by the sudden rupture of an air tight cabin in the stratosphere, when the gas will expand tenfold or if the gut wall cannot give way sufficiently will cause a great increase in gut pressure.

(*c*) The Effect of Reduction in Pressure on the Nasal Sinuses and the Middle Ear

It is true that these spaces are in communication with the outer air by passages which end in either the nose or the back of the throat (fig. 3). The communication is, however, often insufficient or interrupted. Considerable discomfort may arise through changes in pressure if the air in the middle ear or in the frontal sinus and antrum is closed off from the air.

The nasal, frontal, antral, and sphenoidal sinuses have openings to the nose, which are usually adequate to equalize the pressure. These openings may, however, be closed by a swelling of the mucous membranes or by overgrowths, and in acute or chronic colds in the head may be closed by mucus. During a rapid ascent an adequate equalization of pressure usually occurs due to the relatively increasing inner pressure which opens the passage but when descending the rapidly increasing outer pressure serves to close the openings in a valve-like manner. Then the subnormal pressure causes congestion and marked pain. In addition there is the danger that a sudden opening may suck mucus into the cavity and set up an infection.

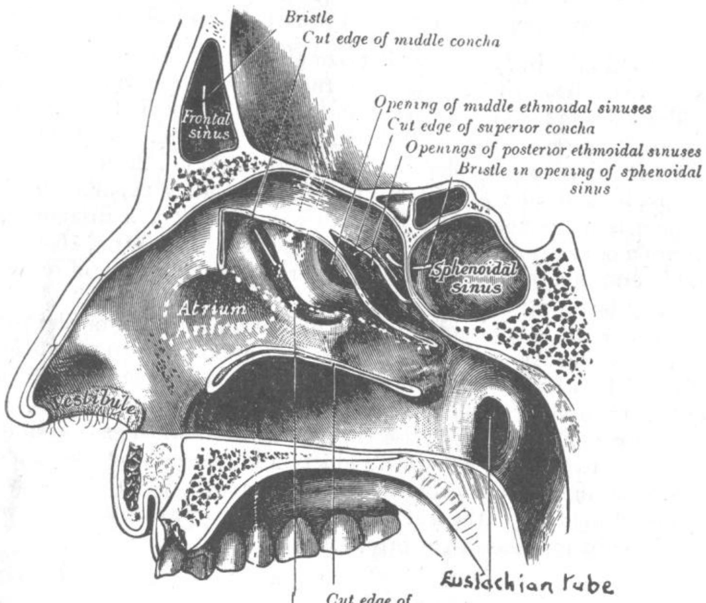

FIG. 3.—After Gray's Anatomy. The frontal and sphenoidal sinuses are shown with bristles showing their openings to the nose. Bristle in antrum, the position of this sinus is dotted. The opening of the Eustachian tube is also shown.

Particular discomfort of this kind is to be expected by persons with large frontal sinuses. They are well advised, even in the case of a mild cold or in any case of blocked nasal passages, to make use of a nasal salve or spray containing such substances as ephedrine which decrease the swelling of the nasal mucosa. As far as possible flights with rapid changes of elevation should not be carried out by

persons with a cold in the head. Persons with an obvious tendency to frontal catarrh are not suitable for the flying services.

The middle ear (the cavity containing the bones connecting the ear drum to the internal ear) is connected with the naso-pharynx by a tube, "the Eustachian tube," and hence with the air (fig. 4).

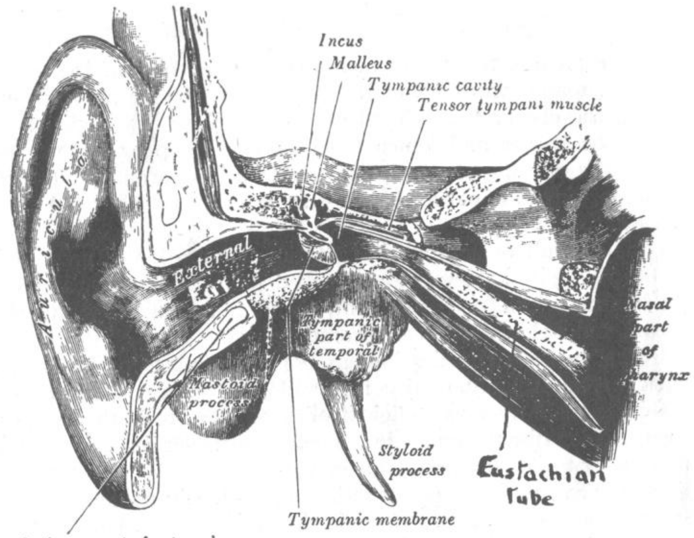

FIG. 4.—After Gray's Anatomy. Section through external ear passage, middle ear (tympanic cavity), and Eustachian tube. The drum (tympanic membrane) separates the external passage from the middle ear and has attached to it the little bones, Incus and Malleus, which transmit the vibrations of the drum to the internal ear (not shown).

If this tube is somewhat obstructed by acute or chronic inflammation of its mucus membrane or if it is not normal in character, acute pain is set up on descending, owing to the failure to equalize the pressure in the middle ear. Even a slight difference in pressure on the sides of the ear drum decreases the hearing. Inadequate pressure equalization leading to this inequality in external and internal pressure may, even in a descent of 3,000 m., 6,500 ft., produce definite pain and cause small haemorrhages in the middle ear. In a descent from

6,000 m., 19,000 ft., a difference in pressure of ½ an atmosphere may be produced. The ear drum is therefore forced in with a pressure equal to a column of mercury 38 cm. high. If this occurs to the pilot, he may be so incapacitated by the pain that the safety of all is endangered. Rupture of the drum even has been produced in this manner.

Equalization of Pressure in the Middle Ear

In most cases the Eustachian tube can be opened by repeated swallowings and yawnings, or if necessary by forcing air in by compressing the cheeks with closed mouth and nose held tightly. The greater the height and hence the difference in pressure, the more difficult the opening of poorly permeable tubes becomes. Therefore it is important to equalize the pressure after every 500 m., 1,600 ft., of descent.

If as a result of a rapid descent the equalization of pressure has not been happily achieved and marked pain supervenes, and if the pain increases with further descent, then a re-ascent till the pain disappears and a slow descent is recommended.

If the pressure equalization has not taken place on landing, the physician can usually rectify it by blowing in air. Sometimes in such cases there remains a slight feeling of pressure in the ear which, however, soon disappears again. Persons with not readily permeable tubes are not suitable for the air service.

In civil aviation changes of altitude are usually made slowly so as to avoid these symptoms. If made slowly enough the equalization of pressure will take place, owing to diffusion of gas into or out of the blood stream.

3. Oxygen Lack and Altitude Sickness (Mountain Sickness)

(*a*) Introduction to Respiration

With increasing height the atmospheric pressure decreases and correspondingly the number of the gas molecules in every litre of air diminishes but the quantitative relationship of the gases, 1/5 oxygen and 4/5 nitrogen in the air mixture, does not change.

For human respiration only the oxygen (O_2) fraction is important. The nitrogen and other chemically "indifferent," that is chemically inactive gases, are inhaled and given out again in the same quantity. If they are entirely lacking, as for example when breathing pure oxygen, this produces no effect on the human organism.

The body requires, in order that its tissues may carry out their

necessary processes, both oxygen and food-stuffs (protein, fat, and carbohydrate). Within the cells of the body the food-stuffs are united with oxygen or burnt to produce water, carbon dioxide, and other waste products. This combustion process furnishes the body with heat. The temperature of the body is kept constant by changing the amount of blood flowing through the skin and is decreased by the evaporation of sweat in higher temperatures and in the case of low temperatures by decrease in the blood flowing through the skin and if necessary by increase in the internal heat production by increased combustion. By these means the body temperature is held at about 37°C. (98.3°F.). In exercise the requirement of the active muscles for oxygen is greatly increased and a corresponding increase in heat production occurs.

The transport of the food-stuffs within the body from the gut or from depots such as the liver, is carried out by means of the blood stream. This also takes up the waste products of the activities of the cells and carries them chiefly to the kidneys for excretion in the urine.

The carriers of oxygen in the blood are the red blood cells. In them the oxygen is combined with the red blood pigment (haemoglobin) (fig. 5), and the amount carried decreases with the oxygen partial pressure and the height. If one remains for some days or more at high altitudes in the mountains, the number of red blood cells increases in order that the increase in number of carriers may compensate for the lessened oxygen load carried by each of them, owing to the decrease in the partial pressure of oxygen.

The most important condition for the adequate provision of oxygen to the body is a sufficient oxygen content in the lungs.

Circulation

The circulation of the blood is intended to supply all parts of the body with oxygen and food-stuffs and to remove the waste products from the cells. Its motor is the heart, a two-chambered pump.

The right heart chamber pumps through the lungs the blood which has flowed to it by the thin walled veins from the minute capillaries in all the tissues. This blood is poor in oxygen and rich in carbon dioxide. In the lungs the blood passes through a great network of fine capillaries which cover the surfaces of the air sacs which form the final endings of the air tubes and of the trachea. In this passage the carbon dioxide is given off and fresh oxygen is taken up.

From the lungs the blood, enriched in oxygen and poor in carbon dioxide, flows to the left heart chamber and from there it is driven with an initial pressure of 160-220 cm. of water through the main arteries to the fine capillaries throughout the body, where again an exchange of oxygen for carbon dioxide and of food-stuffs for waste products occurs.

The blood vessels, both the arteries and the veins, are composed of elastic coats and muscle layers. The muscular coats, by contracting or relaxing, can alter the cross sectional area of the vessels.

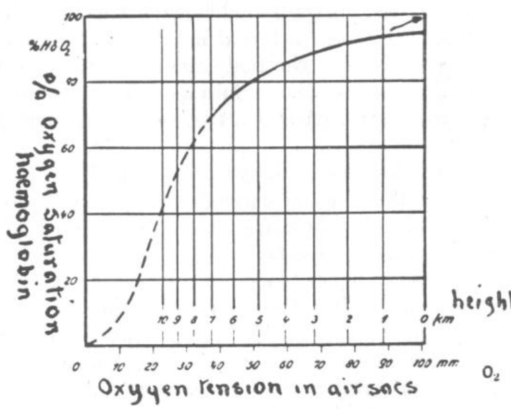

FIGURE 5

Curve showing saturation of the haemoglobin (red blood pigment) on the left, i.e. the degree to which the pigment will be saturated with oxygen. As the partial pressure (tension) of oxygen decreases, less oxygen is combined with haemoglobin. The tensions are shown on the base line and the altitude corresponding to the various oxygen tensions are shown in km. above the base line (3 km. = 9800 ft.; 5 = 16.400; 10 = 32.800).

These muscular coats of the vessels cannot be contracted or relaxed voluntarily, i.e. by means of the will. The tension they exert is, however, regulated involuntarily by their nerves, which in harmony with the respiration so regulate the distribution of the blood as to provide the tissues with oxygen in accordance with their constantly changing needs. Emotional changes may affect their regulation as for example in blushing for shame, when the small arteries of the skin are dilated, while in fright the skin fades, owing to a contraction of the same arteries.

If the nerve centres regulating the circulation of the blood are depressed, as for example by lack of oxygen, the pressure in the blood vessel falls. In this way several litres of blood may be pooled in the

dilated vessels of the lower half of the body. Then the return flow to the heart becomes insufficient (the heart beats when poorly filled), the blood pressure falls, and the blood no longer circulates adequately. This is termed by the physician "circulatory collapse." The circulation through the brain becomes insufficient and unconsciousness supervenes, because the brain cells no longer obtain enough oxygen to carry on their activity.

After long standing, such a sudden general dilation of the vessels is particularly apt to occur. The blood tends to stagnate in the vessels of the lower limbs and in the gut. This is the cause of fainting in such cases. If a person has stood for a time, anxiety lest this accident may occur greatly contributes to its likelihood. Even strong emotions in persons with hypersensitive centres in the brain may lead to such a collapse of the circulation. Such persons are not suitable for the flying service.

Respiration

During inspiration the chest is expanded and the lungs filled by raising the ribs and by the descent of the diaphragm, which separates the chest from the belly. This expansion draws in air through the nose and mouth and the trachea to fill the expanding lungs and the air finally reaches the terminal air sacs. (In the nose the air is partly cleaned and warmed and moistened. This does not occur when breathing through the mouth and therefore breathing through the mouth is unhealthy, since it leads to drying and irritation of the mucous membrane of the lower air passage.) During expiration the chest collapses, due to its weight and the elasticity of the lungs. Only on forcible expiration and during increased respiration does the musculature of the chest and belly contract during expiration.

The essential condition for an adequate oxygen supply to the blood in the lungs is that the oxygen content and partial pressure of the oxygen in the lungs is greater than that in the blood pumped into the lungs by the heart. For the loading of the blood with oxygen is due merely to a positive inward fall in oxygen pressure from the air in the lungs to the blood. When this is not the case the blood would give off some of its oxygen to the air in the lungs and this takes place when a great reduction in the oxygen content of the inspired air occurs (see p. 30).

The oxygen content of the air in the terminal air sacs of the lung is always lower than in the air breathed, because the air taken in is always mixed with the air which has remained in the lungs during expiration and which has lost some of its oxygen content and is richer in carbon dioxide and saturated with water vapour (see fig. 2).

The quantity of air inhaled in an ordinary inspiration is about ½ a litre and hence with the usual 15-17 breaths per minute 6-8 litres are inhaled and exhaled. After a normal expiration some 2 litres of air remain in the lungs. With deeper inspirations and expirations the amount of each breath can be increased to more than double for long periods, especially if the rate of breathing is somewhat slower.

By increasing the amount of air inhaled at each breath the oxygen content of the terminal air sacs is increased, because the amount of the oxygen-rich inhaled air amounts to a greater proportion of that already in the lungs, which is oxygen poorer. The oxygen content of the blood may thus be increased.

In heavy muscular work the respiration may be increased to ten times that of normal resting respiration. Without doing work, such an increase can be carried out only for a very short time, since more carbon dioxide is exhaled than is being formed in the body. A marked decrease in the carbon dioxide in the blood leads to a condition resembling poisoning, with unconsciousness, owing to an increased alkalinity of the blood. Anyone may test this on himself by carrying out rapid and deep respiration for a time. Merely deep, but slow respiration, may be carried out for a long time without lowering the carbon dioxide content of the blood much, even if no work is done. If, on the other hand, the carbon dioxide content of the inspired air is increased, respiration may be increased in rate and depth for a long time at rest, without any disadvantageous effects, as carbon dioxide itself stimulates the respiratory movements.

Our normal involuntary respiration is controlled by the processes of combustion in the body, which produce increased carbon dioxide in the blood and this in turn increases the activity of the respiratory centre in the medulla (the centre which controls the respiratory muscles). Hence every increase in the carbon dioxide in the blood increases respiration so that the excess of carbon dioxide may be blown off from the lungs. In voluntary deep and rapid breathing at rest, more carbon dioxide is blown off than formed and consequently as the blood becomes poorer in carbon dioxide the activity of the respiratory centre would diminish were it not driven voluntarily. If this voluntary drive ceases, then there is a cessation of breathing, to allow the carbon dioxide to accumulate. In an aviator at high altitudes in whom the blood oxygen content is already low, such a cessation might readily be dangerous, because the oxygen content would fall too low. Such temporary cessation of respiration readily occurs when attention is given to the reading of instruments or when observing or thinking deeply.

Improvement of the Resistance to Altitude Sickness by Slow, Deep Breathing

In case one has to fly, for any special reason, at heights above 12,000 ft., without the usual oxygen supply, one should inspire deeply and expire deeply in order to make the proportion of the gas entering the terminal air sacs from the atmosphere as large as possible in comparison with that remaining from the last breath. By this means under suitable conditions the capacity to reach a greater height, even 3,200 ft. higher, can be increased without the flier being much affected, especially if this form of respiration has been previously practised. This type of breathing is also of advantage at great heights, even if oxygen is being inhaled.

In this type of respiration it is important, while increasing the depth of the individual breaths, to decrease their number per minute, so that the total amount of air breathed per minute is only slightly increased.

It is inadvisable and also against regulations, to fly above 4,500 m., 14,700 ft., without an artificial oxygen supply. Quite apart from the fact that such flights are unnecessarily tiring and often cause a long-lasting headache, there is often even in normal persons a decrease in mental capacity and altitude sickness may supervene.

(*b*) Altitude Sickness (anoxæmia)

The cause of altitude sickness is the fall in the oxygen content and therefore of the oxygen partial pressure in the inhaled air to a value inadequate to supply the oxygen requirements of the body (fig. 2).

The conclusive proof of this statement is that the symptoms of altitude sickness disappear at once, if by taking oxygen the partial pressure of the air in the lungs is adequately increased. *Altitude sickness therefore arises from a lack of oxygen* in the inspired air.

A sufficient supply of oxygen for the body tissues can be obtained only when the oxygen content of the blood is higher than in the tissue and there is a sufficient difference in oxygen pressure between blood and tissues.

The cells in the brain are the ones which are most susceptible to a lack of oxygen and on their proper activity depends our accurate thinking. Therefore the effects of oxygen lack in a person sitting still show themselves in a change in his mental capacity and earliest in those highest mental capabilities, attention and judgment.

Here we find a certain similarity to the effects of alcohol, as many persons, both from oxygen lack and from alcohol, lose the ability of self-criticism and this is the reason why persons who suffer from marked inhibitions frequently show more liveliness.

In high flying the decrease in the capacity of a person for self-observation due to oxygen lack is a particular danger because the flier loses his capacity to judge to what extent he is already suffering from altitude sickness and this leads him to neglect to employ oxygen, particularly as a person in this stage of altitude sickness is often, like those under alcohol, in an exaggerated mood of confidence and considers himself particularly capable, while the contrary is in fact the case.

Above 5,000 m., 16,000 ft., most persons can be shown to be definitely less capable mentally, as can easily be shown by tests of writing and questions in arithmetic. The simultaneous observation of several instruments becomes more difficult, and hence, for example, the right moment to adjust the cooling gills of the radiator is missed and the motor is damaged. It can also be demonstrated in the reduced air chamber that the accuracy of shooting is greatly reduced.

This, together with the decrease in the ability to fix the attention on the enemy, leads to a great diminution in fighting ability. Concentrated attention and good shooting are in this latest phase of air warfare the basis for success, while being surprised owing to lack of attention is the most frequent cause of being shot down.

The inability to fix one's attention is particularly dangerous in blind flying over mountains.

In consequence of the decrease in judgment through oxygen lack, photographs which had been taken at 16,500-19,500 ft., of the flier's home territory instead of the enemy's, were brought back during the last war. Opponents suffering from altitude sickness are said to have gaily signalled to each other without firing, which is readily believed by those who have studied the symptoms of altitude sickness.

The danger of death from lack of oxygen at great heights was clearly recognized in 1875 when the Frenchman Tissandier returned from an ascent to between 7,900-8,000 m., 26,000 and 26,200 ft., with his two companions both dead as a result of insufficient use of oxygen. Tissandier himself became unconscious, but was fortunately saved by a descent of his balloon.

Since then altitude sickness has been thoroughly studied in mountain expeditions, in stations high in the Alps, in balloon ascents and aeroplane flights, but particularly by laboratory studies carried out in reduced pressure chambers or by decreasing the percentage of oxygen inhaled. One now knows what occurs and the means of combatting it. But nevertheless at times death occurs at high altitudes

as a result of neglect or carelessness in the use of an artificial oxygen supply.

Even in 1935 the crew of the balloon *Bartsch von Sigsfeld* died of altitude sickness at a height of 10,000 m., 32,800 ft., because they did not appreciate the danger of breathing atmospheric air through the nose when they were obtaining an artificial oxygen supply through a tube in their mouths without applying a nasal clip. And only recently a two seater returned from a flight to 7,500-8,000 m., 24,600-26,200 ft., with an observer dead from lack of oxygen on account of a failure in his artificial oxygen supply. On this flight the machine was only between ten and fifteen minutes above critical height.

Therefore it is essential that every flier who flies at heights above 4,500 m., 15,000 ft., be so thoroughly instructed in the dangers of altitude sickness that he is thoroughly convinced of the necessity of breathing oxygen whenever he goes above 4,500 m., 15,000 ft. He should also be on the outlook for the symptoms of altitude sickness either in himself or in others, owing to the danger of a defect in the artificial oxygen supply. This is particularly necessary since the latest investigations have shown that the lack of oxygen for a considerable time may lead to permanent damage in the brain cells, as a microscopic examination after death has shown. The symptoms of altitude sickness are fundamentally different in persons at rest from those doing heavy work.

Altitude Sickness when at Rest

The lack of oxygen in the inhaled air produces, when one is sitting at rest, no respiratory distress. On the contrary, respiration tends to get less difficult as there is less resistance to the passage of the air through the respiratory passages.

Anyone who has the ability to observe himself during the beginning of altitude sickness will at times be able to notice that his heart begins gradually to beat faster and that the respiration becomes deeper and more irregular. Normally the increasing weariness and lack of desire to move is striking. Thinking becomes slow, calculations become difficult and can be performed only by an increased exercise of the will. A decrease in the sensory activity of the eyes makes the field of vision appear darker.

Altitude Sickness during Exercise

While respiratory distress never arises in persons at rest, even when the lack of oxygen is great, a person doing work at great heights shows marked respiratory distress.

The reason for this lies in the fact that during exercise the combustion in the body is incomplete and acid waste products appear in the blood stream. These stimulate the respiratory centre to greater activity and excessive respirations and hence the sensation of distress. In addition, the increase in acid products causes nausea, headache, dizziness, violent heart beating, and often a feeling of complete loss of power and weakness of will.

This form of altitude sickness occurs relatively infrequently in high flying, because the crew only in exceptional cases, for example in a violent fight in the air at great heights, have to do much work. The symptoms are often observed in high climbers in the mountains, particularly when the climber is untrained, and is then called mountain sickness. The symptoms may appear even when climbing at 3,000 m., 9,800 ft., if there is much muscular exertion.

Small bodily movements while sitting stimulate the respiration and improve the circulation and increase the resistance to altitude sickness. It is therefore important in flights above 4,000 m., 13,000 ft., not to sit quite still. If it be true, as is said, that flights were made at altitudes between 5,500-6,500 m., during the last war without the crew showing observable symptoms, this must have been due not only to the possession of fortunate constitutions and to experience, but also due to the moderate movements attendant on searching the heavens for the enemy and for employing the photographic apparatus.

Marked bodily movements above 4,000 m., 13,000 ft., increase the incidence of symptoms quickly and considerably.

In this connection we wish to refer again to the favourable effect of slow, deep, regular respirations in increasing the ability to withstand high altitudes, particularly in the case of necessity when one is forced to fly at heights up to 6,000 m., 19,700 ft., without oxygen.

Severe symptoms of altitude sickness cannot be observed by the person affected because he has lost the power of self-observation and of judgment.

The incapacity to carry out co-ordinated movements, for example when writing, the occurrence of twitchings in the muscles, the rapid increase in heart rate, and the increasing irregularity of respiration, are usually no longer observed, or if they are, attention is no longer paid to them. In this condition the altitude sick respond to orders either slowly or not at all. Gradually the decrease in thinking ability passes over into unconsciousness. The involuntary muscular twitching increases till there are convulsions and finally respiration ceases. The circulation fails and with the final stoppage of the heart death occurs.

The capacity to withstand high altitudes varies extraordinarily in different persons and in any individual varies greatly with his physical

state, lack of sleep, alcohol, nicotine; and fever or exhaustion particularly greatly decrease his capacity and may lead to a decrease in his resistance to altitude by as much as 1,000 m., 3,300 ft. Hence in such cases great caution must be observed.

An increase in body temperature greatly decreases the capacity of the blood to combine with oxygen. In animal experiments it was shown that a temperature of 3°C. decreased the resistance to altitude by 3,000 m.

Many persons can recognize the beginning of altitude sickness with sufficient assurance if they have been previously instructed in a low pressure chamber or by using an apparatus for reducing the percentage of oxygen. Others will become altitude sick without being able to observe any warning symptoms. In most persons the slight symptoms pass gradually over into severe ones with unconsciousness, while the circulation still remains relatively normal. There are, however, persons who without warning pass into a serious stage of altitude sickness owing to a failure of the circulation. These are the altitude collapse types, which the medical examination should guard against, as they would be dangerous pilots and must not be so employed, as even though they may withstand the effect of altitude in general well, nevertheless their circulatory collapse may occur without warning.

This circulatory type of collapse is much more difficult to control by the use of oxygen than the ordinary altitude sickness because it is just the circulation which fails and this is required for the transport of oxygen from the lungs and although the blood in the lungs may become rich in oxygen, not enough per minute is supplied to the brain and medulla owing to the failure of the circulation.

Occasionally in such cases life may be saved by the injection of strong heart stimulants (adrenaline, V.E.H.) and artificial respiration which, by the alternate compression and expansion of the chest, mechanically helps to force the blood along.

Fitness for High Flying

The ability of individuals to endure oxygen lack and therefore the fitness to carry out high flights varies greatly. We can most conveniently divide people into

1. Very suitable persons,
2. Sufficiently suitable ones,
3. Those less suitable,
4. Those unsuitable.

In regard to 1—

The very suitable persons are those who show a great resistance to the effects of altitude and in case of failure of the oxygen supply at great heights have a great "interval of reserve," i.e. there is considerable time before they have symptoms.

Only such persons should be entrusted with the piloting of machines with large crews in flights over 8,000 m., 26,000 ft., because they offer an assurance that they will notice the changes in themselves and also in the members of the crew.

For flights above 10,000 m., 32,000 ft., only particularly suitable persons should be in charge, because at this height even unobserved defects in the oxygen apparatus may lead rapidly to death.

In regard to 2—

Sufficiently suitable persons are those who do not differ in their ability to withstand heights from normal persons. These persons above 5,000 m., 16,000 ft., show no tendency to circulatory collapse but show only gradually increasing symptoms of altitude sickness so that only above 6,000 m., 19,600 ft., are severe symptoms to be expected.

In regard to 3—

Less suitable are persons whose resistance to altitude sickness is low and in whom the "interval of reserve" is short and who rapidly become sick due to oxygen lack.

Such persons should only in exceptional cases be in charge for flights over 7,000 m., 23,000 ft., and must then pay strict attention to the functioning of their oxygen apparatus.

In regard to 4—

Quite unsuitable for employment in the flying service are those who show a tendency to the collapse type of sickness, particularly as the weakness of their circulatory system makes them prone to be affected by centrifugal force.

Zones of the Effects of Altitude

According to H. Strughold we can recognize the following zones of the effects of altitude (fig. 6).

1. *The Indifferent Zone.* That within which height produces no effect on the normal individual. This usually extends to 3,000 m., 10,000 ft.

2. *The Zone of Adjustment,* where there are definitely observable effects. Within this zone the readaption of respiration and circulation is adequate to compensate for the effect of height if no marked physical work is done. The transition to this zone is known as the "threshold of reaction."

3. *The Zone of Incomplete Compensation.* The threshold of this zone lies about 4,000-5,000 m., 13,000-16,400 ft. It is bound above by the "critical threshold" which leads into the zone of death due to altitude.

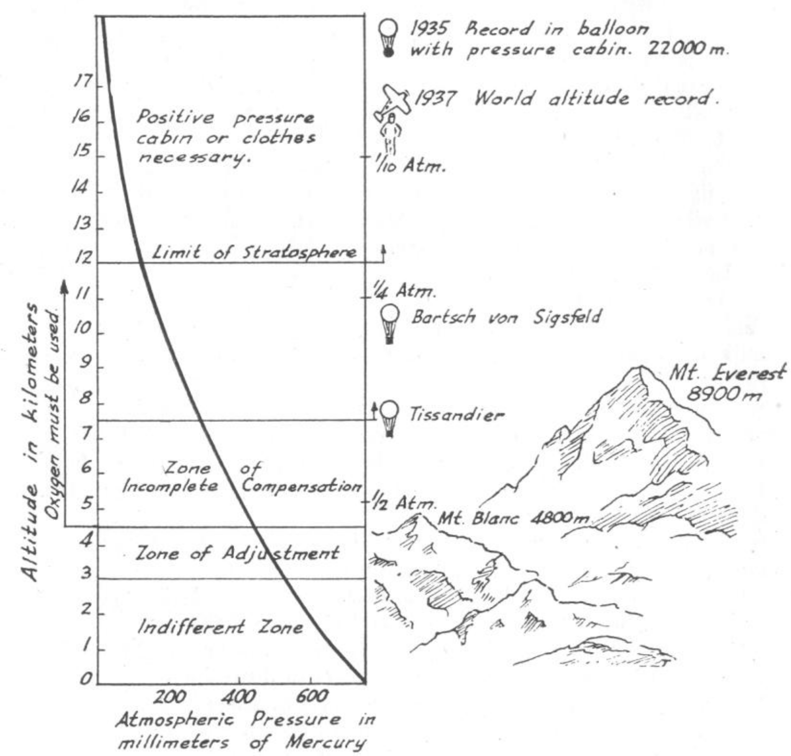

FIG. 6.—The curve indicates the decrease in atmospheric pressure with altitude in kilometres on the left. The various zones referred to in the text are shown and on the right the comparative heights of mountains and of the heights attained in the air by man.

The period of time spent in high altitudes naturally has an influence on the symptoms of altitude sickness. With increasing height, the greater the duration in the high altitude the greater the effect produced.

The Interval of Reserve after Cutting off Oxygen

At different heights the "interval of reserve," i.e. the time till the occurrence of symptoms after cutting off oxygen, is distinctly different. This interval of reserve is of the greatest practical importance. Hence this term "interval of reserve" was introduced by H. Strughold. This interval differs greatly in different persons and varies in the same person with the conditions of his health. For example, at 16,400 ft., this interval of reserve was found to vary from 5 minutes to over 1 hour in different individuals, and at 19,600 ft., between a few minutes and half an hour, at 22,900 ft., from 1 minute to half an hour and at 26,200 ft., between 10 seconds and ¼ hour.

On account of the great practical importance of this interval for high flying, it should as far as possible be ascertained for each individual when he is undergoing his testing, so that each flier would know how much time he would have to repair a failure in oxygen supply or to descend to a safer level.

The zones of the effects of altitude (see p. 27) differ greatly for each individual and vary again with his physical condition. The individual variation is rarely more than 1,000 m., 3,200 ft., for each height.

The indifferent zone usually extends to 3,000 m., 9,800 ft.

The Zone of Adjustment extends on an average to 13,000-16,400 ft., in normal individuals who have not been for a long time in the mountains. Its threshold lies 3,200 ft. lower in those who have been doing work.

Adaptation to height in persons who have been for some days at elevations over 19,600 ft., may extend to 22,900 ft.

The critical threshold for death may in normal persons under unfavourable circumstances extend to just above 6,000 m., 19,600 ft., while usually it lies about 7,000 m., 22,900 ft., although the interval of reserve decreases rapidly and the danger of death increases rapidly.

The climber who had great resistance to the effect of altitude might, under the most favourable conditions, just reach the highest mountain peak in the world, that of Mount Everest, which is 29,000 ft. high, without the use of oxygen. This is the greatest possible attainable height, even for a person adapted to high altitudes.

For flying personnel it would suffice in theory that they could stand satisfactorily 4,500 m., 14,700 ft., without an oxygen supply. Above

14,700 ft., the oxygen supply must, without question, be employed.

In practice, however, one must reckon with a failure of the oxygen supply or neglect to employ it. Therefore it is important that the high flying personnel should, as far as possible, maintain their resistance by training and by care in living. For the same reason unnecessary flights without oxygen should be avoided as far as possible, since the resistance is impaired for future flights.

Therefore high-flight training by repeated flights about 14,700 ft., without oxygen must be forbidden unless under medical supervision.

The use of alcohol before high flights must be scrupulously avoided because alcohol greatly reduces the resistance to altitude and none should be taken in the 8 hours preceding a flight.

4. Respiration with an Oxygen Supply and the Use of the Respiratory Apparatus

The preceding paragraphs have shown us that the activities of the body are closely dependent on a sufficient oxygen supply in the air.

If the oxygen content of the inhaled air is decreased considerably in any manner, human capacity is greatly decreased and death may be produced if the oxygen lack is great. We have seen that during an ascent the oxygen content of the air becomes less and this induces altitude sickness.

In order to prevent altitude sickness, the maintenance of the oxygen content must be assured during a flight. This is achieved by the addition of oxygen to the inspired air by means of a special breathing apparatus. If intelligently used this will provide an adequate oxygen supply up to about 12,000 m., 39,000 ft.

Regulations require the use of the Breathing Apparatus above 4,500 m., 15,000 ft., in order that acute dangers and lasting damage to the human organism be avoided and particularly to avoid the insidious beginning of altitude sickness which occurs at about 5,000 m. and which by its decreasing the attention and observing power of the crew may seriously endanger the attainment of the objective of the flight. In addition, the increasing lack of judgment as to his condition, both mental and physical, may lead to even further ascent, or lead to remaining at a critical height too long without the flier even thinking of employing the Breathing Apparatus, so that a dangerous state due to oxygen lack may arise. During war every decrease in flying ability and in the power of attention and observation due to oxygen lack must be strictly avoided. Therefore it is particularly necessary to use intelligently the Breathing Apparatus in every case above 4,500 m., 15,000 ft.

At 5,000 m. in general amongst normal persons no dangerous symptoms of sickness are to be expected, but above this point the respiration of air alone leads increasingly rapidly to the production of severe air sickness.

The interval of reserve after cutting oxygen off at 6,000 m. lasts on the average somewhat more than 15 minutes, at 7,000 m., 23,000 ft., only a minute or so, above 8,000 m., 26,200 ft., unconsciousness may occur in less than a minute. And above 9,000 m., 29,500 ft., the rapid loss of any oxygen in the blood to the lungs may cause death in seconds. This may be illustrated by the report made by W. Neuenhofen, once holder of the world height record.

Part of the Report of W. Neuenhofen over a Height Record Flight, Dessau, 12.6.1929

"At the height of 5,000 m. I began to use the Breathing Apparatus and found to my misfortune that the tube which led to the mouth was too short. Therefore I was greatly handicapped in looking out of the machine which was necessary to maintain my orientation. I could have gone down again to have the apparatus replaced as it had been set at a lower level than before, but as I had the official instruments on board I wished to fly the machine to its ceiling. Up to 10,000 m. all went well, then I became somewhat nervous because my respiration was difficult on account of the short tube and it fell several times out of my mouth when endeavouring to look out. Then it happened that my left eye, which was watering, froze. I flew therefore without goggles because the formation of ice made them useless to see through. I admit fully that I did not feel happy because it was no longer possible to get my orientation. But a man's will is his heaven and I wanted to break the record. So I reached 11,500 m. when my left leg became suddenly ice cold. I had just time to let go the control column and the button on it which short-circuited the spark to the motors and hence led to them stopping. Then I became unconscious. When I came to I was at 4,000 m. and 45 km. east of Dessau. I took at once the direction to the flying field and landed with the last drop of gasoline in the tank. The attempt to break the record had failed."

Ignorance of the dangers of high flying and lack of schooling in the use of the Breathing Apparatus leads to a neglect to employ this aid in the maintenance of flying capacity and endangers the safety of the flight. Above 7,000 m., 23,000 ft., death threatens if the breathing of oxygen is insufficient and has already claimed many victims.

Hence every flier must be thoroughly instructed in the technical details of the Breathing Apparatus and in the type of defect to which it is liable.

The Breathing Apparatus

The apparatus is an arrangement which provides the user with an air-oxygen mixture with increased oxygen content and at great heights pure oxygen. It does not manufacture oxygen but provides for an adequate supply from tanks of compressed oxygen.

The Oxygen Apparatus

This apparatus is designed to supply extra oxygen mixed with air or at greater heights pure oxygen. It does not produce the oxygen but provides an adequate supply from pressure tanks.

In the last world war oxygen was not supplied in tanks but as a fluid in pressure flasks of Dewar type (like a thermos bottle) in which the space between the walls was exhausted. The advantage was that liquid oxygen gives off per litre 5 times as much oxygen as 1 litre of oxygen compressed at 150 atmospheres.

The disadvantage lay in being unable to store liquid oxygen as it continually evaporates. It is also difficult to add just the required amount of oxygen to the inspired air. The same is true of a piece of apparatus that made the oxygen. It has not yet proved advantageous to use the type of rebreathing apparatus used in case of accidents in coal mines, etc., though with this type of apparatus the consumption of oxygen can be reduced to about 1/10 of that of the oxygen apparatus now used, as in the rebreathing type only enough oxygen is supplied to replace that used by the body. This is when sitting still and quiet only about 250-300 ccm. per minute. During severe work the amount may increase to 2-3 litres a minute (nearly 10 times). The ordinary type of oxygen apparatus must, on the other hand, supply the whole amount of inspired air, which at rest is 6-8 litres per minute and during severe work may be 100 litres. In a fight in spirals the machine gunners may use 50-60 litres.

In foreign countries this ordinary type which is wasteful of oxygen is frequently used because if the face mask is not tight the continuous flow of oxygen makes it more reliable. In our automatic types of oxygen apparatus furnished by Auer and by Draeger, the adaptation of the amount of oxygen to the requirement is provided by a special end valve activated by the slight suction of inspiration. The valve is controlled by a breathing bag which is slowly emptied during inspiration. The walls of the bag are connected to a lever which opens the end valve for the admission of oxygen and closes the valve when the bag is filled again.

Description of the Draeger Type (figs. 7 and 8)

On opening the valve (3) on the oxygen tank the oxygen flows to the apparatus through a connecting tube. The connecting tube has a side branch to a pressure gauge (1), or this can be placed as in the figure as a part of the apparatus proper (8). The oxygen flows through

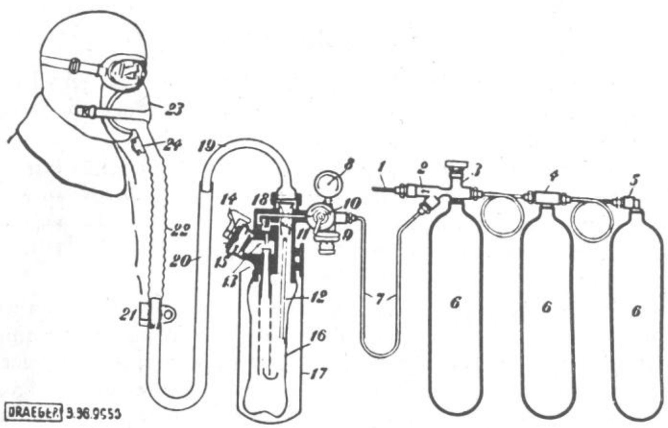

FIG. 7.—Plan of the oxygen apparatus (of Draeger) as described in text.

a pressure reducing valve (9) and a turn off cock (10) to an end valve. If this is closed the oxygen flow is arrested. The end valve (11) is controlled by the lever which is connected to the breathing bag. On inspiring, the air is sucked out of the breathing bag. The walls fall in and take the lever with them. This movement opens the end valve. Oxygen streams in and also an injector (15) is activated which sucks in a certain amount of air. These fill the bag again. From the bag the air passes by the breathing tube (20) to the mask (23) and so to the lungs. The end valve delivers as much air as is required. This apparatus can only function perfectly if the breathing bag is connected air tight to the face, mouth, and nose, since otherwise the necessary slight negative pressure (on sucking in of air) on inspiration does not put the automatic mechanism into operation. Also atmospheric air may be drawn in from the leak in the face piece and breathed.

At the end of the inspiration when the lungs are filled and expiration begins, the breathing bag is distended by the incoming air and oxygen and the lever closes the end valve.

The air inlet through which air passes to the injector is provided with a sliding valve. The lever of this valve (15) is provided with a scale graduated from 0-6 km. for heights from 4,000-6,000 m. On

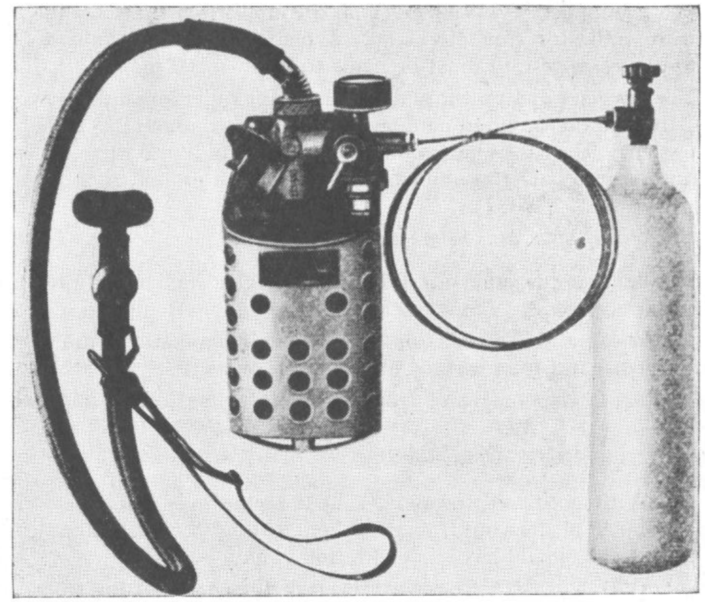

FIG. 8.—The oxygen apparatus manufactured by Draeger.

model A824 Auer, this valve is graduated for 4,600-8,000 m. This type has no reducing valve but the end valve operated by the activity of the lungs withstands the full pressure of the oxygen tank.

The respiration is not made more difficult by the inhalation of the outer air as the injector is activated by the oxygen pressure and does the work of drawing in the air.

Above 6,000 m. the lever of the sliding valve of the air inlet of the Draeger type is closed and hence air cannot enter and pure oxygen is breathed. This lever must not be forgotten when going above 6,000 m.

Theoretically it is only over 10,000 m., 32,000 ft., that pure oxygen is required. Since, however, the respiratory mask rarely fits absolutely tight and small leaks may be expected, the air inlet should certainly be closed at 8,000 m. The respiration of pure oxygen at lesser heights is not harmful but is costly.

The employment of this apparatus requires attention. The oxygen comes from one or more tanks; as soon as a tank is empty no more oxygen is supplied. As this gives no warning, from time to time the pressure indicator must be read. When the pressure falls to 20 atmospheres, a descent must be made to below 4,500 m.

The oxygen requirement of a person sitting quiet amounts to about 1.5-2 litres of tank content per hour of usage; this is about 225-300 litres of oxygen. The tanks have usually a content of 2 or 5 litres. They are united into batteries and can be filled from a ground supply.

Testing of the Apparatus before a Flight

1. Whether the tanks are filled with oxygen, i.e. show a pressure of 150 atmospheres.

2. Whether the connections from tanks to apparatus are tight. Fat or grease must not be used at any joints or valves.

(Notes on the sources of trouble, fitting of mask, etc., omitted.)

While in use above 4,500 m.—

(*a*) With mouth respiration. Take the mouthpiece into one corner of the mouth, breathe out from the other. (Many persons cannot learn to do this and should have an expiration valve.)

(*b*) With a mask. Connect the mask tube to the tube from the apparatus. Exhaled air goes out through the outlet valve.

(*c*) Open the cut off valve.

(*d*) Set the sliding valve to the height.

(*e*) From time to time read the pressure gauge.

(*f*) From time to time (every 5 minutes) and after movements of the head, test the tightness of the fit of the mask and the outlet valve.

(*g*) If the apparatus goes out of order suddenly above 8,000 m., fill the lungs with oxygen and hold the breath if possible until repair or till a descent has been made. The respiration can be held for about one minute.

Also, in jumping with a parachute the lungs should be filled with oxygen and the breath held as long as possible.

(*h*) If the apparatus fails slowly, then a descent must be made as quickly as possible, as no oxygen supply in the lungs is available.

(*i*) On descending below 4,500 m., disconnect.

(*j*) Respiration of pure oxygen is harmless, better begin too soon rather than too late with oxygen.

After landing—

(*a*) Shut off valves.

(*b*) Disconnect mask and mouthpiece, take them with you, they belong to you.

(*c*) Clean masks and the mouthpiece with warm water containing a disinfectant. Wipe them and dry them with warm air (not over 60°), not over a heater or in the direct sun as this damages the rubber.

(*d*) Disconnect breathing tube from the apparatus and clean and dry it. Reconnect.

General Remarks in Regard to Breathing at High Altitudes

The use of the Breathing Apparatus and the adjustment of its parts must be thoroughly learned on the ground in the aeroplane and particularly its controls and the use of the mask.

Every flight above 4,500 m., 15,000 ft., must be used for instruction in the use of the apparatus.

During a fight in the air the use of the apparatus and the provision of adequate oxygen and training in its use assures moral and mental superiority over the opponent.

One should train oneself in deep and smooth respiration and in this, as in training for long races, more attention should be paid to deep expiration than to inspiration. One avoids doing without the apparatus above 6,000 m. and one trains oneself to quiet breathing with it, even when the attention is otherwise directed.

It is not necessary to breathe more than usual. This increases unnecessarily the use of oxygen and makes the body poor in carbon dioxide so that respiration becomes finally irregular and quite unfavourable.

The higher one is to fly the more necessary it is to see that the apparatus is in good order.

If one begins to breathe oxygen from the apparatus after a period of oxygen lack, it is advisable to breathe only to a normal depth, because otherwise for a few seconds the altitude sickness becomes temporarily, but considerably, greater.

Above 12,000 m., 39,000 ft., even when breathing pure oxygen, the supply of oxygen to the body becomes rapidly inadequate. At this height it is no longer possible for even a person sitting quiet to obtain the oxygen partial pressure in the terminal air sacs of the lungs, which corresponds to the partial pressure of oxygen at ground level. In spite of breathing pure oxygen at 14,000 m., its (partial) pressure will not reach the partial pressure of oxygen which is present when breathing air at 5,000 m., and at 15,000 m., the oxygen pressure only corresponds to about 7,000 m., with air (fig. 2).

It is true that in a flight in an open cabin and without oxygen supply, 14,860 m., 48,000 ft., was attained but the pilot found himself in this short record flight at the utmost limit of what was bearable. He was severely altitude sick and feared unconsciousness every minute.

In order to provide for flights above 12,000 m., 19,000 ft., and to enable the crew to avoid altitude sickness and to lead to the crew being capable of movement and activity, it is necessary to increase the air pressure on the personnel artificially.

For this purpose the positive pressure cabin and positive pressure clothing, have been used.

5. Flights in Positive Pressure Cabin or in Positive Pressure Clothing

The building of a positive pressure cabin entails no particular technical difficulty as a positive pressure of ¾ of an atmosphere suffices to supply the crew with adequate oxygen even when breathing an air artificially maintained at the composition of normal atmospheric air (such a cabin was built by Junkers into a plane in the year 1928 and technically was quite satisfactory).

A positive pressure suit (fig. 9) can only be employed with much less positive pressure because otherwise only arms and legs can be moved unless the suit is provided with joints which are extremely difficult to make. In it one looks like a blown-up rubber animal, which even with low internal pressure possesses a certain rigidity.

Since at present the pressure in a positive pressure suit can only be 1/3 of an atmosphere, the oxygen content of the inhaled air must be increased. Breathing pure oxygen and with a positive pressure of 100 mm. Hg. at even 30,000 m. a supply of oxygen to the lungs which would correspond to that at 4,000 m. can be attained. (The supply of oxygen while in this pressure suit is best supplied by a circulating rebreathing apparatus because this method saves oxygen while absorbing carbon dioxide.)

The positive pressure suit has the great advantage over the positive pressure cabin in that it can be used in any type of aeroplane without any change in construction. Hence for these reasons the positive pressure suit has been used for the latest height records in spite of the difficulties in movement that it entails. With it a height of 16,440 m. has been attained.

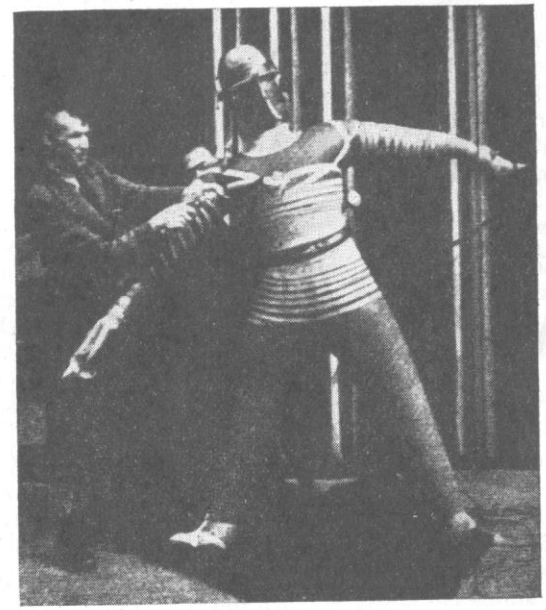

FIG. 9.—Positive pressure clothing inflated.

Report of the Italian M. Pezzi over the Positive Pressure Suit Worn in a Record Flight

"The suit worn by me consisted of an absolutely impermeable rubber combination and of a metal helmet connected with it. The helmet contained numerous windows which were electrically heated to avoid frosting. In order to prevent the rubber suit from expanding too much it was covered by a second stiffened cloth combination. The helmet was carried by a metal breast-piece which distributed the weight. The difficulties that had to be overcome were great. Above all it was difficult to prevent the internal pressure making the suit too rigid and its taking the form corresponding to the greatest volume. This was overcome by decreasing the pressure within the suit. The first idea was that a difference of pressure between the in- and outside of 3/10 of an atmosphere would be sufficient. This would enable the pilot to be as well off at 16,000 m. as in the air at 5,500 m. This pressure can be borne for a long time when oxygen is being breathed. As a protection against the cold, an electrically heated suit was worn inside the rubber one, which would assure a proper temperature at the −60° to −70° existing in the stratosphere.

The heights reached by the selected personnel were the limits attainable and could only have been attained by well-trained and experienced fliers. Such heights can only be attained and used for traffic when the problems of the positive pressure cabin have been solved. The positive pressure suit is unsuitable for this purpose."

The advantage of breathing oxygen in a positive pressure suit is the decreased risk of bodily damage due to a sudden fall of pressure. If in a positive pressure cabin machine at 15,000 m., which is filled with air, there is a sudden fall in pressure due to breaking a window or to a shot hole, the pressure falls in a few seconds, and nitrogen bubbles will escape into the blood stream and plug the minute vessels of the brain and lungs.

If in a positive pressure cabin pure oxygen is breathed for some time, the nitrogen gradually disappears from the blood and tissues and the danger of the production of gas bubbles disappears.

Further, in such a sudden fall in pressure the gas in the intestines rapidly expands, producing a considerable pressure in the abdomen, if the precaution has not been taken to get rid of any gas or prevent its occurrence by proper diet.

The symptoms of bends disappear in descending, due to the increase in atmospheric pressure.

Unconsciousness is to be expected within a few seconds in the crew of a positive pressure cabin if it is ruptured at 12,000 m. if atmospheric air has been breathed, as the blood loses its oxygen extremely rapidly. If oxygen can be breathed, it is possible even at 14,000 m. to postpone altitude sickness for a few minutes. Whether it is possible above 14,000 m. to maintain consciousness for a minute so that the pilot has the chance with a forced dive to attain a bearable height, has not been settled.

Animal experiments have shown that a guinea pig after breathing oxygen can survive a fall of pressure from atmospheric to 20 mm. Hg.

(corresponding to a height of 25,000 m.) within five seconds without any permanent severe damage, if the pressure is again lowered to correspond to 19,600 feet within a minute and a half. Therefore the possibility must be considered that the crew of a ruptured positive pressure cabin could be saved if an automatic mechanism were provided to send the plane into a fast glide to a lower level. A reduction of altitude of 9,800 ft. in a minute is surely not impossible to provide technically, particularly as the rare atmosphere at this height presents little resistance.

In order to avoid the passengers having to employ an oxygen apparatus in flights over high mountains in America, an air-tight cabin is provided in which, without having a positive internal pressure, they breathe air which is artificially enriched in oxygen and deprived of carbon dioxide and of water vapour. If the oxygen in such a cabin is maintained only at a partial pressure equal to that of ordinary air, there is no danger of fire and smoking can be safely carried on.

6. The Danger of Breathing Toxic Motor Gases

From a powerful aeroplane motor there is given off about 1 cubic metre of exhaust gas a second. Therefore in an open aeroplane the crew is endangered by the exhaust gas if it is not led away completely.

This is often difficult because the aeroplane constructor wishes as far as possible to avoid long exhaust tubes, as they decrease the efficiency.

In an enclosed aeroplane the external air streaming past the body may produce a decreased pressure in the pilot and passenger cabin as compared with that without, and suck in oil fumes and gas from places that are difficult to detect. Changes in paint covering or small dints in the external walls may so influence the air currents about the body of the aeroplane that a plane previously free from exhaust gas may suddenly be filled with a toxic carbon monoxide concentration.

Before the dangers of the inhalation of exhaust gases were recognized and constructors took precautions to guard against it, it was found on examination of the crew that even after an hour's flight there were definite evidences of exhaust gas poisoning (fatigue, dizziness, headache, nausea, and depression).

The poisonous action of exhaust gas depends chiefly on carbon monoxide. The proportion of this gas is least during ordinary flying when the combustion is good, greater in a throttled flight, and particularly strong when the motor is running free.

The content of lead in exhaust gas when tetraethyl gasoline is used is so small in comparison with the dangers of carbon monoxide, that repeated carbon monoxide intoxications would occur before any damage worth talking about from lead could occur. Nevertheless, the presence of lead in the exhaust gas makes the smell definitely less agreeable and in persons susceptible to such odours may definitely increase the tendency to altitude sickness and after the flight leave them without appetite.

For the same reasons, constructors should use every endeavour to prevent oil vapours reaching the pilot or crew, since the oils evaporated from running motors owing to their disagreeable smell even when they are present in quantities that are chemically undetectable, produce nausea and decrease the gastric activity in susceptible persons. The gases in the exhaust due to burnt oil (aldehydes and acrolein) are irritants to the mucus membranes in extremely low concentrations and may produce gastric irritation by being swallowed with the saliva. Nevertheless the poisonous character of these substances is much less than that of carbon monoxide. Therefore, in general, an aeroplane may be considered as hygienically satisfactory if the concentration of carbon monoxide is not above 0.0025% in air (i.e., about ¼ that allowed in factories).

As carbon monoxide definitely increases the effects of height, the research bureau has for years insisted on this standard.

Carbon monoxide has an affinity for the oxygen-carrying pigment of the blood (haemoglobin) 300 times as great as that of oxygen. Consequently the symptoms of altitude sickness may occur even at sea level if the air breathed for 4-5 hours contains 0.05% of carbon monoxide, because in this time about one-half of the haemoglobin will be united with carbon monoxide and can no longer transport oxygen. In industry even 0.01% of carbon monoxide is not allowed for hygienic reasons (fig. 10).

Such a diminution of the oxygen-carrying power of the blood and consequent decrease in the oxygen supply to the tissues would naturally produce very marked effects at high altitudes when the oxygen load carried by the blood is in any case decreased. For example, at 4,000 m. when the blood in the lungs is only 85% saturated with oxygen, breathing 0.02% carbon monoxide for an hour reduces the oxygen saturation to 77% and in four hours to 70%. Such a decrease in the oxygen saturation by carbon monoxide may lead to the occurrence of severe altitude sickness at 4,000 m.

In this connection it must also be remembered that not only the oxygen supply for the crew but also that to the motor falls at high altitudes, and that if the motor is not equipped with a supercharger,

the combustion in the motor becomes less complete and the content of carbon monoxide in the exhaust increases.

The occurrence of exhaust gases in the inhaled air is particularly dangerous at heights between 3,000-4,500 m., since the oxygen apparatus must be used above 4,500 m. This makes one practically independent of the outside air and is the best protection and even the best treatment for poisoning with exhaust gases. Consequently it is

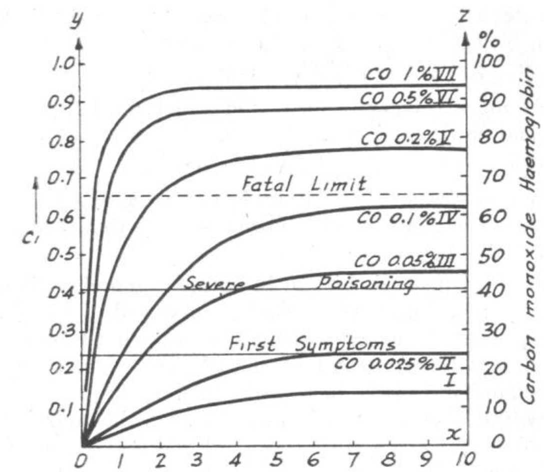

FIG. 10.—The various curves represent the rate at which the haemoglobin becomes combined with carbon monoxide when it is present in various concentrations in the air. The figures on the base represent hours. Symptoms of poisoning are only produced in some six hours by 0.0025%, but it would tend to increase altitude sickness at an earlier period.

important to make use of the oxygen apparatus at even lower altitudes if there is a suspicion of contamination by exhaust gases.

If the oxygen apparatus fails the additional effect of carbon monoxide at heights above 6,000 m. is dangerous to life, as even small amounts greatly decrease the interval of reserve and increase the rapidity of the onset of symptoms, and at heights below 7,000 m. may produce unconsciousness in a few minutes and death.

Therefore the occurrence of exhaust gases in the pilot cabin or in the plane which is to fly high must be at once reported and rectified.

7. Important Suggestions in regard to Protection against Cold and Special Clothing

With increasing heights above sea level the temperature of the air falls on an average 6°C. for every 1,000 m., 3,200 ft., elevation to the stratosphere level at 12,000 m. Above this the air temperature is uniform throughout the year at −50° to −60°C. (fig. 2).

Therefore every high flier, even in summer, and every flier in winter must be protected by special clothing against undue loss of heat and frost bite, if his cabin is not electrically heated.

The cooling of the body is dependent upon:

1. The temperature, movement and moisture of the surrounding air, and on the heat from the sun,
2. The protection provided by clothing,
3. The blood flow through the skin which is regulated involuntarily by the nerves. (The mechanism resembles that of an automatic refrigerator.)

The warming effect of the sun in an open aeroplane is quite unimportant in comparison with the cooling produced by the air currents created by flying. In an enclosed cabin, particularly one protected by glass or some transparent material like cellophane, the warming effect of the sun's rays may be considerable.

The absolute moisture content of the air, i.e. the quantity of water vapour contained in the air, increases considerably the cooling effect of the air by increasing the conduction of the heat from the skin. The water vapour content of the air decreases rapidly with falling temperature so that air at −10°C. may be regarded as practically free from it (fig. 11). Therefore we feel less cold at times on dry frosty days than on damper days with a temperature about freezing.

The loss of heat from the unclothed or lightly clothed body increases almost directly with the speed of the wind. For one who wears suitable clothing for protection against cold, the loss of heat with increased speed is inconsiderable. Nevertheless, it is necessary to decrease as much as possible any draught on the pilots or in the cabin, as every strong draught disturbs the crew and is found very uncomfortable, particularly on the face.

The materials most suitable for flying clothes are those which contain much air in their interstices, such as knitted materials and fur, since the ability to retain heat and protect against cold depends chiefly on the air enclosed in the material and beneath it, since air at rest is a very bad conductor of heat. Hence we can keep a cooking vessel warm for a long time if we put it in a box loosely filled with hay

or straw, between whose stalks there are large air spaces. On the same principle depends the protection against cold of loose paper within high boots.

It is also important that the clothing should not flap about and that the air in them should stay still. Otherwise the warm air next the skin comes to the surface and loses its heat and the cold air will penetrate to take its place.

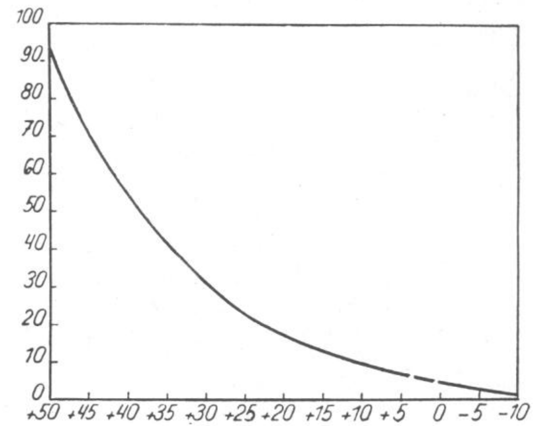

FIG. 11.—Curve showing that the content of water vapour expressed in grams per cubic metre (on the left) of air fully saturated with water varies with the temperatures shown in degrees centigrade on the base line.

The outer layer of the clothing must be wind-proof but permeable to water vapour so that the water vapour produced by sweating may be evaporated, because moist clothing is a much better conductor of heat and a poor protection against cold. As a wind-resistant, but permeable outer coat, the "English leather" has been valuable. Also true leather is wind-resistant and permeable. Naturally the underclothing must be permeable to water vapour. Rubber clothes are therefore to be avoided for fliers.

The underclothes must be able to absorb large amounts of sweat, as in summer before high flights much sweat will be secreted.

A thick shirt and long drawers protect against too rapid evaporation of sweat and the resulting unpleasant feeling of coolness of the skin.

A thick wool jacket should be worn under the coat but the coat should be big enough for it. Otherwise it is better to use the wool jacket alone. Gloves and stockings must not fit so tight that they obstruct the important flow of blood through the skin.

For the protection of the hands from cold in an open cockpit is recommended

1. An under layer of loosely fitting linen or silk,
2. The usual fur gloves with wristlets (gauntlets),
3. Roomy mittens of nappa leather lined within with lamb's wool. (These easily removable mittens can be fastened to the gauntlets' cuffs with a rubber band.)

Such a hand covering will protect against cold even when flying in an open cockpit for many hours at low temperatures.

Heated Garments

If electrically heated gloves are available, one can do without the heavy mittens. If the hands and feet alone are warmed electrically, they must not be warmed too much, as otherwise there will be a marked dilation of the skin vessels of the body also, and consequently a great loss of heat. The flier is deceived by the feeling of warmth that an increased blood flow produces, nevertheless the heat loss is greatly increased (like a motor car in winter without a shield to its radiator). Therefore if the hands and feet are alone warmed, great care must be taken that they are not warmed too much.

It is much more advantageous for long flights at low temperature to wear a suit electrically heated so that all parts of the body will be kept equally warm. Such suits are today available.

For the feet two pairs of loosely fitting ski stockings within the boots are recommended. Fur boots must also fit loosely over the shoes and it is an advantage if within the overboots there is a thick cork sole in order to decrease the transmission of cold from the foot control.

The protection of the face against cold in an open cockpit is difficult. It is inadvisable to wash the face or shave just before a flight. A good preventive treatment of the face with oil or a skin cream is recommended. Particularly good is a thorough rubbing with "nivea cream."

The salve to protect against frost bite must be put on in a layer as thick as a razor blade. This salve usually consists of animal fats with some camphor and must not contain water because as this freezes it may damage the skin. It is recommended that in summer a small

supply of the protective salve should be taken with one and applied subsequently; this avoids sweating under the salve which is uncomfortable and decreases its usefulness considerably.

The face must, as far as possible, be so protected with goggles, respiratory mask, or other protective mask and flying scarf that no skin is visible. This is quite possible but requires some dexterity.

The respiration mask must be fitted air tight in order to protect the oxygen supply and also in order that the moist breath will not be expelled so as to coat the goggles with ice. If there is a tendency for the breath to escape around the edges of the mask, the trouble probably lies in too tight an escape valve.

This coating of the goggles may be difficult to avoid when flying in an open cockpit, and a pair of electrically heated goggles is an advantage.

If flying without a mask, the flier may draw the scarf tight below the goggles over his nose and mouth and wind it round his neck. Dependent on his facial form and personal experience, each flier will in time find his own mode of using and fastening the scarf.

In an open flight in marked cold, the flier should from time to time feel his face so as to ascertain whether it is covered and to notice whether any part has lost its sensation by frost bite. Such places must be rubbed thoroughly at once in order to increase the blood flow.

If such frost-bitten areas are only discovered after landing, the areas should be rubbed with snow if possible and in no case should they be thawed with warm water or before a fire. Frost bites manifest themselves in redness, swelling, and blisters, and leave an itchy, pricking, painful feeling. The physician should at once be informed, as such areas have a greatly lowered resistance to infection and must therefore be protected against it.

During high flights it is extremely important to prevent undue loss of heat by adequate clothing, because if the body becomes cold, shivering takes place as a means of producing more heat and this entails a greatly increased intake of oxygen. Shivering is always an indication that the body can no longer be kept warm by decreasing the heat loss by constricting the skin vessels and that increased heat production must be provided through shivering, with its attendant increase in oxygen consumption.

A lack of oxygen decreases the warmth, particularly of the hands and feet, and hence the breathing of oxygen over 4,000 m. is also useful to prevent getting cold.

C. THE EFFECT OF ACCELERATION AND OF CENTRIFUGAL FORCE

1. Physical Introduction

In order to understand the effect of velocity and centrifugal force in aviation on the human body, certain fundamental ideas from physics must be recalled.

The first is velocity, the expression for the distance travelled in a unit of time Velocity $= V = \frac{\text{metres}}{\text{sec.}} = m/s$. At once the question arises: What velocity can a man in an aeroplane stand? The answer is simple. Man, if adequately protected against the pressure of the wind produced in flying, can withstand any velocity if it remains constant in its rate and direction, that is to say if there is no acceleration or retardation or change of direction of the movement. We are moving all the time at a velocity of 30 km., 12.4 miles per second with the earth around the sun without being conscious of it, because our surroundings are moving with us. Consequently the speed of a motor car or an aeroplane has no effect upon those in it, save that of the shaking and vibrations which accompany its progress, as long as the means of transport does not change its direction or its speed. If we hold out a hand from the window we feel at once the resistance of the air which is streaming past. The air resistance increases as the square of the velocity of the aeroplane relative to that of the air.

Therefore if a man falls out of an aeroplane at normal air density he will acquire no higher velocity in falling than about 60 m., 152 ft., per second, 210 km., 130 miles, per hour. According to the law of gravity, a body falling in empty space must by the force of gravity acquire a constantly increasing velocity. But in a space filled with air the force of the air resistance reaches in a few seconds the value of the force of gravity. When these two forces, gravity and air resistance, balance each other, the falling body is no longer accelerated.

The final velocity of free falling in an air-filled space is naturally different for each type of body. The factors concerned are the specific weight of the body and the air resistance. An aeroplane in a vertical dive (with cut out motors) reaches a final speed of 100-200 m., 330-680 ft., per sec., 360 km., 224 miles, to 720 km., 447 miles, per hour, dependent on the type of its construction.

If the velocity of a person jumping out of an aeroplane is more than 60 m./second, this velocity is reduced in a few seconds to 60 m./second. This is of practical importance in the case of parachute

jumping from an aeroplane falling at high velocity and led to the development of the so-called "manual" parachute which can be loosened voluntarily after jumping and allowed to unfold after the air resistance has cut the speed of falling to the normal value. Consequently the strains imposed on the parachute when opening can be reduced to the lowest possible amount.

Formerly the so-called "anchored" parachute was employed and still is in the slower pleasure aeroplanes. This parachute was opened by a cord attached to the aeroplane about 5 m., 15 ft., long, that is when the velocity of the jumper differed but little from that of the aeroplane itself.

[According to the law of inertia, any body maintains a constant velocity and consequently an unchanged energy of movement (kinetic energy) when all forces applied to it equalize each other, i.e. when the sum of all the forces is nothing. If this equilibrium is changed by the preponderance of any of the forces the body changes either its rate or the direction of its velocity and gains or loses correspondingly in its (energy of movement) kinetic energy.]

The force that is necessary to impart a certain increase in velocity to an object, i.e. to overcome its inertia and increase its kinetic energy, is directly dependent on its mass. This conclusion finds its expression in the formula Force = Mass × acceleration.

According to the law that all bodies attract each other in proportion to their masses, the earth exerts an attraction which accelerates all freely falling bodies in a direction towards its centre. If any body can respond to this force without any resistance, for example can fall freely in empty space, then, since the force of attraction and inertia increases in the same proportion, there will be an increase in velocity, an acceleration of 9.81 m. second per second which is independent of the mass of the body and its weight; that is to say it will be accelerated by gravity about 10 m., 32 ft., per second. This is the acceleration imparted by the earth's attraction and we will designate this in the following as 1 "g" and will use this symbol also for gravity itself.

If a body is resting on a support, e.g. a table, it cannot be moved by the force of gravity because the support does not give way. It presses on the support due to gravity and this gives the body its weight. To measure the weight we can use a spring which is extended or pressed together by the weight until the tension in the spring equals the weight of the body produced by gravity. We weigh in this way with a spring balance.

If on a spiral spring in a case we hang a series of weights, we can make a scale in the multiples of the first weight. We have then an indicator of the force of acceleration on which we can read off directly in multiples the force of gravity (fig. 12).

Example 1. If a flying machine is started with a catapult which imparts an acceleration of 3 × 9.81 m. per second, that is an acceleration of $3g$ in a horizontal direction, then a person sitting in the machine will, on account of his inertia (resistance to movement), be pressed

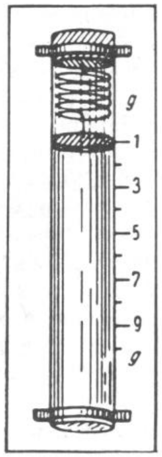

FIG. 12.—Diagram showing the principle of an acceleration indicator. A spiral spring supporting a weight. A centrifugal force will lead to the spring being more stretched by the weight. Its scale is in gravity units.

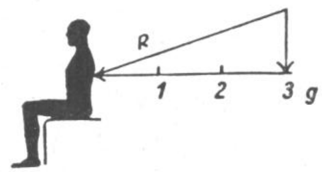

FIG. 13.—Two forces are represented as acting on the seated person, one, the lower line due to the acceleration imparted by a catapult to the aeroplane which has a value to 3 g gravity units, and the other the vertical line of a value of 1 g, representing the force of gravity itself. The resultant of these two forces is R, the third side of the triangle. Its value will be the square root of the sum of the squares on the two other sides $\sqrt{1^2 + 3^2} = \sqrt{10}$ = about 3.3 g.

against the back of his seat with a force equivalent to 3 times his body weight. Since, however, the force of gravity is also present, two forces are acting to give a resultant which has the value of 3.3 g as shown in the diagram (fig. 13) and is directed forwards and downward. The physical effect in a person sitting when thus catapulted, is as if they were tilted back about 60° and had suddenly become 3.3 times as heavy.

Example 2. If an elevator ascends with an increase of velocity of 5 m., 16 ft., a second imparted within one second, the acceleration is

about ½ that of gravity which is 9.81 m./sec. or ½ g. A passenger sitting on a chair then has two forces acting, that of his inertia (weight), i.e. 1 g, and also that of acceleration and both in the same direction, i.e. 1.5 g. He is forced into his chair by 1½ times his weight. The acceleration indicator would read 1.5 g.

If the elevator descended at the same speed the passenger would be pressed into his chair with half his weight only.

In calculating the force of acceleration, b (expressed in multiples of the value of gravity) due to the changes in velocity $(V_a - V_e)$ and for that occurring due to changes in velocity due to acceleration or retardation the following formula is employed

$$b = \frac{(V_a - V_e)^2}{20\, s} \cdot g.$$

If the velocity is reduced to nothing by applying the break or if it can be increased from nothing, then the formula becomes

$$b = \frac{V^2}{20\, s} \cdot g,$$

that is the accelerating force expressed in multiples of g corresponds to the square of the velocity divided by 20 times the distance in metres during which the breaking acts "s"

b = the force of acceleration in multiples of the force of gravity g
g = 9.81 m./s the acceleration imparted by gravity
s = the distance in metres during which the "breaking" retardation occurs
V_a = the initial velocity } in m./sec.
V_e = the final velocity } in m./sec.

Example 3. The final velocity of a man falling from a height of 1,000 m., that is in air of approximately normal density, amounts to about 210 km., 130 miles per hour or 60 m./sec. If it is assumed that the opening of the parachute occurs during a distance of 30 m. = s then there is a uniform retardation from an initial velocity V_a of 60 m./sec. to V_e, a final velocity, of 5 m./sec. (As a fact the retardation imparted by a parachute is not so uniform.) If these values are used in the formula

$$b = \frac{(60-5)^2}{20 \times 30}\, g = 5\, g.$$

To this must be added the man's weight. Consequently the jumper hangs on the supporting straps during the opening of the parachute with a weight of 6 times his own.

A man falling freely to the earth would strike it with a force which would drive him into the earth some 25-50 cm., 10.2-19.6 inches, depending on the character of the ground. The distance through which his velocity would be retarded would be 25-50 cm.; this calculated in the terms of the force retarding his motion would amount to 360 to 720 times the force of gravity, 360-720 *g*. The force of striking would if he weighed 75 kgm. = (360-720), 75 or 27,000 to 54,000 kgm. or 60,000-120,000 pounds.

Example 4. The speed of descent of a parachute jumper is about 5 m., 16.4 ft., per sec. If on landing his knees bend so that they produce a retardation during a movement of 50 cm., 1.6 ft., his force of impact is $\frac{5\times 5}{20\times 0.5} = 2.5\ g$ that is including his own weight 3.5 *g*. The jumper must then support 3½ times his weight, which is quite possible as experience has shown.

The following examples are intended to stress the value of arrangements against blows, protective upholstering, and protective helmets.

Example 5. The landing speed of a modern front line fighter is often 105 km., 65 miles per hour, about 30 m./sec. If there were a uniform rate of retardation over a distance of 200 m. to a stop, the force would equal 0.45 *g*. That is to say, the crew would be thrown forward with a force of 0.45 their weight. In a landing with greater breaking and a stoppage in 10 m. this increases 20 times, that is to 9 *g*, and on running into a fixed object so that the stoppage distance is only 1 metre, with collapse of the plane, it becomes 90 *g*.

If this example is thought out it is easily understood why in general an abrupt landing goes so smoothly for crew, if well strapped in if the aeroplane upsets or slides over the ground for 20-30 m.

Example 6. A pilot who has omitted to fasten his shoulder straps has to make a forced landing in an unfavourable field. The under carriage breaks on an irregularity in the ground and an upset follows. In this case the pilot strikes his temple on an unupholstered part of his seat and with the relatively slight relative velocity of his head as compared to that of the aeroplane of 2 m./sec., which is only the speed of a moderately fast movement of the hand.

If we suppose the distance of retardation by the compression of his skin and the displacement of the bones of his skull is 1 cm., the calculation according to our formula gives a value of 20 *g*, that is if his head weighed 5 kgm., a striking force of 20 × 5 = 100 kgm., 220 lbs. If the surface hit by his head is only 1 cm.², then this is equivalent to 100 atmospheres $\left(1\ \text{at} = \frac{1\ \text{kgm.}}{1\ \text{cm.}^2}\right)$. It is easily understood that the skull could not withstand this impact and would be broken.

If, however, the flier under the same condition struck against an upholstered surface and wore a helmet, the distance of retardation would be greatly increased and the area of impact also. One might assume a retardation distance of 2 cm. and an increase in the surface of impact to 5 cm.² There results a decrease from a value of 20 to 10 *g*, or of the force to 50 kgm., and in place of 1 cm.², 5 cm.² of impact surface gives a reduction in pressure from 100 atmospheres to 10, which the skull can easily withstand.

This example is meant to illustrate the importance of upholstering on the flier's chair and on the instrument board, etc. It emphasizes the importance of the belly and shoulder straps and of the helmet.

Many fatalities might have been avoided if a clear physical understanding of the value of protective upholstering, of strapping arrangements and helmets, had led to their scientific employment.

Every flier ought to be fully aware that it is easier to replace a machine than a fully trained pilot, observer, or radio operator. This applies also to the descent with the parachute from a damaged plane which the pilot would naturally be the last to leave.

The Buckling In

The belts are intended to unite the pilot firmly with his seat, for only in this way does he have the proper sensation of being completely at one with his aeroplane.

The most important strap is the belly belt which must be strapped tight so that its lower edge lies on the groin to hold the thigh firmly on the seat. The shoulder belt is intended principally to prevent the upper part of the body being violently thrown forward in the case of an accident and hitting like a hammer. This is as true for the other members of the crew as for the pilot, if there are shoulder straps for them.

In strapping in for a trick (acrobatic) flight, it is advisable to fasten the shoulder belt first as otherwise the belly belt will be drawn up too high and the buckle will press uncomfortably on the stomach. If they are properly adjusted, the weight of the body is equally borne by the two belts when flying upside down.

The only acceleration in a forward direction that needs to be considered is when being catapulted. It amounts then to three, or not more than five, times that of gravity and acts through 1-3 seconds. The forward acceleration on starting or on giving gas in the air is relatively very much less and in the fastest pursuit planes does not amount to 1 *g*.

Important negative changes in velocity, retardation, occur during the opening of a parachute when the acceleration acquired during falling is suddenly decreased by the open parachute and in the landing at the end of a parachute jump and finally in accidental falls of the aeroplane or in abrupt forced landings. In this latter case the retardation may produce a force which is many hundred times that of gravity which would lead to the complete destruction of a human body.

2. The Effect of Linear Acceleration

The effects of acceleration in one direction on any person are of the order of magnitude of a catapult start and not great, though at times they may obtain a value of 4 *g* acting during 2 seconds. But the crew in a catapult start should press themselves back in their seats so that all parts of the body are carried forward by the acceleration. This prevents the production of an additional acceleration by the swinging back of the body.

Were we to imagine a plane starting like a sky rocket, and which would attain a speed of 1000 m./s or 3600 km./hour in merely 20 seconds, the effect would be equivalent to 5 *g* which when applied to a man in the direction from back to breast can be resisted for a considerably longer time.

In a normal parachute jump the jerk imposed by opening is about 5 *g* and lasts for some seconds. In the case of the "anchored" type of opening, referred to above, from a falling plane or in a forced jump at low altitudes with the immediate opening of the parachute, the rate of fall of the jumper may be more than 60 m./s. And in such cases the jerk during opening may reach a value considerably greater than 5 *g* and the harness may cause definite injury.

Landing from a parachute jump requires, in order to avoid injury, particular attention and skill, especially if the ground wind is strong or squally. Therefore it is necessary that the jumper, through practice on the ground, prepare himself in the technique of landing. In this a rolling away of the body should be particularly practised. By this movement the hard impact is converted into a rolling movement and hence lengthens the time of retardation and lessens the force of the impact.

Even if it does not appear necessary to train the full personnel in parachute jumping simply because one or other of them may have to make a jump in case of necessity, it is important that they should all practise the training in landing on the ground as a sport and that they have at least the theoretical knowledge so that they may in necessity jump clear of the plane and know how to avoid injury during landing.

In jumping from an aeroplane one should endeavour to jump as far as possible from the body of the aeroplane in order to avoid being entangled in the supports of the tail.

For this reason the "manual" parachute opened by hand should not be opened for three seconds, if the height allows of this, and if possible only when the earth is visible, that is when the face is towards it and the back upwards.

Before landing the jumper should endeavour, by swinging movements about the long axis of the body, to turn himself with his back to the wind. On landing he should hold the legs together, relax the body and on striking the earth, the body is to be rolled in the direction of the wind (see p. 91) like the roll in gymnastics, the surface of the hand downwards and the finger tips inwards.

If the wind is strong the jumper should run forward in the direction of the wind, which allows the parachute to collapse. If this is not possible owing to wounds or to too strong a wind, the lowest attaching ropes should be drawn upon, which collapses the parachute.

3. The Stresses Due to Centrifugal Force

If an aeroplane is to change its direction, i.e. to make a turn or climb upwards (to zoom), the crew are pressed into their seats by the centrifugal force and when flying upside down are pressed into the shoulder harness.

The aeroplane, if properly flown, should be turned so that the resultant of the two forces, gravity and centrifugal force, should be directed at right angles to the surface of the seat. (In fact this resultant is slightly inclined to the longitudinal axis of the aeroplane, since the aeroplane raises its angle of pitch slightly in a turn, which is sensed in a blind flight as a position of ascent.) If this were not achieved, the aeroplane owing to the force of gravity would slip inwards or due to the centrifugal force would skid outwards. A plummet (a weight on a string) must hang, during a perfect turn, directly downwards towards the seat with a slight inclination forwards, and a water level, which serves in a direct flight as an inclinometer, must remain directly in the middle during a correct turn.

The resultant of centrifugal force and of gravity can be measured exactly like that due to acceleration by a spring balance whose scale indicates a multiple of the weight hung on it (see p. 48). If, therefore, such an indicator shows a force of 5 times gravity, i.e. 5 *g*, any person would be pressed into his seat with 5 times his weight and the aeroplane also has to withstand a stress equivalent to 5 times its weight.

The value of this increase in weight due to centrifugal force can readily be obtained in multiples of gravity by the following formula

$$b = \frac{V^2}{10r} \cdot g \text{ (gravity units).}$$

The weight increase due to centrifugal force is equal to the square of the velocity in m./s divided by 10 times the radius of the turn in metres.

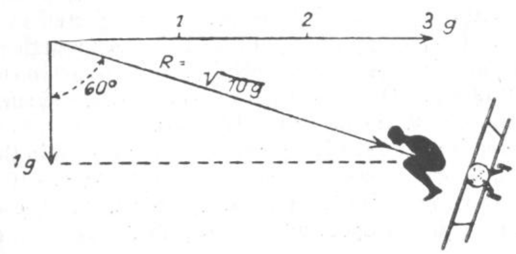

FIG. 14.—In this figure the centrifugal force due to the turn is of a value of 3 g (the upper arrow), the force of gravity is indicated by the downward arrow, the resultant of these two forces is again the $\sqrt{10}\ g=$ about 3.3 g.

Example. An aeroplane circles round the flying field at a speed of 360 km., 220 miles, per hour = 100 m./sec., with a radius of 500 m., 1,640 ft. The centrifugal force is then $b = \frac{100\times100}{10\times500} \cdot g = 2\ g$. The resultant of this force and gravity is $\sqrt{1^2+2^2} = \sqrt{5}$ about 2.25 g. If the centrifugal force amounts to more than 5 g, gravity may be omitted in calculating the force arising in making turns in the horizontal plane, for the error amounts to less than 5%. The aeroplane in this case turns with its wings almost vertical because the resultant of the centrifugal force and gravity is almost horizontal.

In an ideal turn of 45° the centrifugal force is always 1 g and the resultant $\sqrt{2} = 1.3g$.

Every experienced flier trained for pursuit and dive tactics knows that the effect of a high centrifugal force due to banking or zooming may lead to disturbances in vision, as the fliers say "seeing stars" or a "mist in the eyes" or finally as the "black curtain" (a black-out). Disturbances of consciousness have also been frequently observed.

Therefore it is important that the flier and also the constructor know what centrifugal force acting for a given time will produce a complete lack of vision or will lead to unconsciousness, and whether we now or in the near future can keep the crew free from disturbances of vision or unconsciousness in our new pursuit planes when banking or zooming.

In this connection we will in what follows be concerned with the following questions:

1. With what magnitude and during what period must we reckon on stress produced by centrifugal force?
2. What disturbances are produced by high centrifugal forces in the aeroplane and how are they to be explained?
3. Where does the limit lie of what is bearable as regards centrifugal force?
4. How can we best resist high centrifugal forces and which persons are particularly suitable in this regard?

(*a*) THE MAGNITUDE AND TIME INTERVALS

The strongest centrifugal forces are experienced in the course of dive bombing and air combat by fighter aircraft.

In a bombing attack the bombs are often released in an almost vertical dive at a speed which may be above 310 miles/hour and are released when the aeroplane is only 2,200-1,900 ft. above the ground. Immediately the bomber must ascend to avoid the ground, for the diameter of the curve that must be made to zoom from a vertical dive at 310 miles/hour must be at least 1,600 ft., if overstraining the machine by the centrifugal force is to be avoided.

At a speed of 310 miles/hour, theoretically a zooming curve with a diameter of 1,600 ft. and a loss of 1,600 ft. in height must be carried out in 4 seconds and the centrifugal force will amount to 4 g. In fact, the curve in zooming is not that of a circle but rather that of a portion of an ellipse. The radius of the curve will therefore be less and the centrifugal force more, even though the aeroplane loses speed when climbing. In the case of a "proper" climb from a vertical dive at 310 miles/hour in a diving bomber (Henschel H S 123) with a loss of 1,600 ft. in height, the writer measured the force as 8.2 g and during 2.8 seconds of the curve at more than 7 g. The entire time taken by the change of direction was 6.5 seconds. The pilot was then pressed into his seat with a force of 7-8.2 times his weight and his blood would become heavier than iron.

In zooming out of a vertical dive at 310 miles/hour from a height of 1,300 ft., the radius of the curve must be so small that the centrifugal force would be greater than the strength of a fighter plane as it would amount to 12-13 times that of gravity. The aeroplane would have either to hit the earth or go to pieces in the air due to the excessive strain imposed upon it.

In order to give the pilot of the diving bomber enough time to recognize his objective and to attain it, an air brake has recently been devised which reduces the speed to under 279 miles/hour.

In general the centrifugal force in recovering from a vertical power dive seldom exceeds 8 *g*, and then only for 1-2 seconds. Centrifugal forces of more than 12 *g* have occurred, and pursuit planes have gone to pieces in the process.

Most of the new pursuit planes and fast bombers attain a speed of more than 310 miles/hour in a horizontal flight. In a steep dive they will often attain a speed of 447 miles/hour = 656 ft./sec. At such speeds changes of direction may set up centrifugal forces of 8 *g* and over. Stresses due to centrifugal forces lasting longer than 2 seconds are rare today and probably will be in the near future.

The Value of the Acceleration Indicator for the Regulation of the Centrifugal Force

At present the regulation of the strains due to centrifugal force in turning and dive recovery is left to the indefinite sensations and the strength of the pilot's arm, and these are subject to great personal variations.

The elevators can, it is true, be manipulated in most aircraft flying at high speeds only by a strong use of force, but a powerful pilot in the midst of a fight can break the aeroplane in flight, particularly if during or shortly previous to manœuvering the aeroplane is trimmed tail heavy. Also the physical effort required to manipulate the controls during a fight may increase altitude sickness.

If the necessary expenditure of force is to be held to moderate amounts, then to avoid an undue strain on the machine and crew, an acceleration indicator which will show the centrifugal force is necessary (fig. 12).

By the constant employment of such an indicator the pilot can soon learn to combine the reading on the scale with the feeling of stress so that he can pilot his aeroplane with greater certainty and avoid any dangerous stress due to centrifugal force.

As yet the instructions for the personnel of pursuit and fighting planes are very incomplete in regard to the stresses due to centrifugal force which lead to disturbances of vision and unconsciousness. This is unfortunate, as under certain circumstances not only passing

disturbances of vision but long-lasting disturbances of mental activities may be expected from the effects of centrifugal force.

Modern pursuit planes can be broken by too fast a recovery from a dive by pulling back the control column too harshly. Even during flying at a horizontal speed of 224 miles/hour a turn may result in centrifugal forces of 8-9 *g* and at 310 miles/hour a value of 14 *g* may be reached. In the former case the strength of a bomber and in the latter that of a fighter may be exceeded.

Quite apart from disturbances of vision and consciousness, persons standing in the aeroplane may suffer broken bones, especially of the lower leg, by unexpected sharp turns, even if the centrifugal force does not exceed 3-4 *g*. A force of more than 5 *g* produced by centrifugal force, which rarely occurs in the modern multiseater aeroplane, cannot be withstood in the standing position as a rule, and therefore such a force must not be employed with standing personnel.

It is also very important that the pilots of the modern high performance aeroplane, e.g. diving and fighting aeroplanes, may be enabled to watch over their own resistance to centrifugal force so that they may drive up to their personal limit but not exceed it unnecessarily. For this purpose the acceleration indicator is necessary in the instrument board.

For the trick (acrobatic) flier the acceleration indicator in the recording form is a valuable help as an objective guide. The manœuvres his machine makes in regard to their duration in time and their smoothness (fig. 15) are recorded and can be studied.

Finally the inclusion of a "highest acceleration indicator" (that is an instrument which merely shows if a previous set acceleration is exceeded) may prevent an unnoticed overstraining of the strength of the aeroplane and thus the rough flier, who is inclined to fly so as to cause undue stress on machine and personnel, can be watched over and trained.

Probably many experienced fliers will protest against the installation of a new instrument in the instrument board. But quite apart from the fact that such an indicator requires little space it is probable that its installation will have to be carried out merely on the grounds of flying safety.

Conclusion

In conclusion, our observations of front line modern aeroplanes have shown that the expected stresses due to centrifugal force may amount to 9 *g* which will force the crew into their seats with 9 times their weight. (In individual cases short-lasting forces of 12 *g* have been observed.) Centrifugal forces over 6 *g* rarely last more than 8 seconds, since a change of direction of 180° at a speed of 720 km., 447 miles, per hour when the centrifugal force is evenly applied lasts only 7.5 sec. Experience has shown that in fights in the air and in power diving a force of 8 *g* lasts usually only 2 seconds and not more than 3.

Apart from experimental flights carried out for technical construction reasons and those made in medical experiments, the centri-

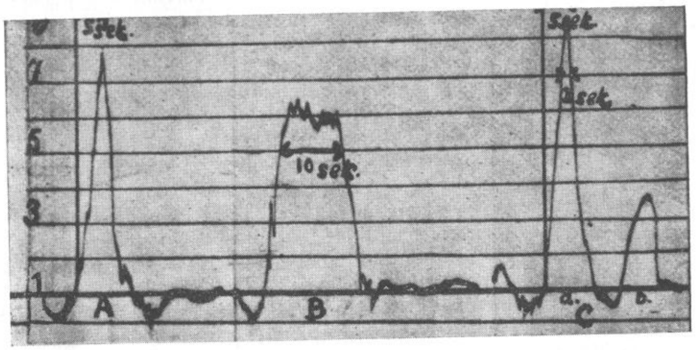

FIG. 15.—Record made by a recording acceleration indicator showing at (A) the centrifugal force developed during the recovery after a dive at 450 km. per hour; (B) during a spiral; (Ca) recovery after a dive at 500 km. per hour, (b) during a loop.

fugal forces will not increase essentially in the near future, even in pursuit and bombing planes. This can be readily predicted with sufficient probability from the curve representing the technical developments of flying.

(*b*) THE CAUSE OF THE DISTURBANCES AND THEIR EXPLANATION

Persons standing in a plane may suffer severe injuries if the centrifugal forces pass a certain intensity, or if the resultant of gravity and centrifugal force does not fall on the area on which they stand, owing to faulty handling resulting in slipping or skidding of the aeroplane.

Powerful muscular persons when standing can sustain a force of 4 *g* for 10-15 seconds if they are prepared for the strain and if they have the proper stance. Two persons were able to withstand the increase

of fivefold their weight by centrifugal force when standing, that is to about 400 kgm. for 10 seconds, although their vision was lost owing to deficient blood supply to their eyes.

In as far as possible centrifugal forces of more than 4 *g* should be avoided and even then a pilot with standing personnel must take great care that all turns, horizontal or vertical, should be smoothly executed, with no skidding or slipping, which will throw the resultant of the forces beyond the area of stance.

Since forces of 4 *g* can be produced easily in the modern fighting aeroplanes when turning or zooming from horizontal flight, it is distinctly advantageous that the pilots should be trained by the use of an acceleration indicator so that they can recognize the strength of centrifugal forces and keep them moderate.

Persons sitting in an aeroplane may suffer the following disturbances:

I. Those occurring during the normal increase in centrifugal force, which is short-lasting.
   (*a*) The visual disturbances which occur in 1-2 seconds after the force is applied and quickly disappear as the centrifugal force diminishes. These are the well known "gray veil" or "mist before the eyes" which, if the force is greater, becomes the "black-out," the total loss of vision with consciousness retained.
   (*b*) The same disturbance together with temporary loss of consciousness.

II. The deep, long-lasting loss of consciousness due to the centrifugal forces overstraining the circulation and leading to a circulatory collapse (collapse due to excessive strain).

III. A very transitory disturbance of vision with a slight clouding of consciousness after a short zoom upwards.

The disturbances of vision and consciousness most frequently observed occur only 1½-2 seconds after the beginning of the centrifugal force and end almost with its cessation. Dependent on the magnitude of the force the disturbances are more or less marked. These disturbances are rather thoroughly described as follows.

A very slight disturbance consists in a "gray veil." The outlines of the objects under observation, instruments, etc., become no longer sharp. They appear as though they were seen through a mist, which becomes thicker as the force increases and thins as it decreases. With increasing centrifugal force the mistiness passes into blindness, which is described as the eyes becoming black or "blacking black" (in English in original) (a black-out). Consciousness is quite clear and thinking undisturbed.

If in the exceptional case consciousness becomes cloudy or unconsciousness supervenes, this returns immediately if the force ceases or if by bending forwards a better blood supply to the brain is produced, as this bending forward decreases the height to which blood has to ascend from the heart to the head.

The Cause of the Visual Disturbances Due to Centrifugal Force

A few years ago the literature presented the view that these visual disturbances and unconsciousness were due to the pooling of the blood in the abdominal vessels which lay below the heart and that the blood supply to the brain became inadequate. The Englishman Marshall sought to prevent this pooling in the abdominal vessels by the employment of a belly belt. And also it was suggested that the abdominal muscles should be voluntarily contracted by speaking the letter "i" during the centrifugal force.

Most experienced investigators in the medical field today advance the view that a stress due to centrifugal force, which amounts to more than 5 *g* if it lasts longer than 3 seconds, can be only sustained without disturbance in exceptional cases, and that the usual limit lies between 4-5 *g*. They believe that any essential increase in resistance to such disturbances cannot be produced by training or by the use of special arrangements.

It did not appear to us that the position outlined above was adequate because the effects of centrifugal forces on mankind had been very little studied. Consequently, in order to find means of increasing the resistance of men to stress and centrifugal force, it appeared necessary to know where in the body these forces had their most marked site of action. In order to investigate this in Germany, the Ministry for Air had thorough investigations carried out on a special centrifuge in the laboratory and in flying machines.

As a result of these investigations there is no longer any doubt that disturbances of blood flow in the retina of the eye and in the brain are the cause of the disturbances. Their chief causation lies in the increase in weight of the blood due to the centrifugal force and the change in the circulation that this produces and which shows itself both in the general circulation and especially in that of the eye and brain.

Corresponding to the centrifugal force the blood becomes heavier and hence the pressure differences within the vascular system are changed by the increase in the blood weight.

The pressure differences produced by gravity due to the height of the brain above the heart and of the legs, for example below it, are normally not important due to the manifold, fine regulatory arrangements in the circulation, which maintain an adequate blood flow through each of the organs. Nevertheless, sick persons with low blood pressure and damaged circulation, may suffer such visual disturbances and even loss of consciousness if they get up suddenly out of bed because their blood pressure being low, the head, when elevated some 20-30 cm., 9-12 inches, above the heart, no longer obtains sufficient blood.

If centrifugal force acts upon the body to the extent of 5 *g*, the blood becomes five times as heavy and the fall in pressure in the brain arteries, as compared to the blood pressure at the heart, due to the height of the brain above the heart, becomes five times as great.

The changes in the circulation in the brain are such as would occur were the height of the brain above the heart increased proportionately to the increase in the weight of the blood due to centrifugal force. This is represented graphically in fig. 16, and in this diagram it is clearly shown that of the blood pressure at the heart (shown as the upright line) the effect of centrifugal forces leaves less and less pressure available in the vessels of the brain (indicated by the heavy line), until this becomes quite inadequate to produce a proper brain circulation.

In a 20-30 year old man the blood pressure in the great artery leaving the heart is almost 120 mm. Hg., which corresponds to a column of water 160 cm. high. Of this, 30 cm. of pressure is lost under normal conditions of gravity. If a centrifugal force of 5 *g* comes into effect, $5 \times 30 = 150$ cm. of the water pressure is lost and only 10 cm. of blood pressure remains in the arteries of the brain. That does not suffice for its blood supply and the blood supply to the eye arises from a branch of that supplying the brain. The lack of oxygen arising from the lower effective pressure leads to a complete loss of vision and to unconsciousness.

A fall in blood pressure in the arteries to the brain is particularly unfortunate for the eyes and vision because in the eye there is normally an internal pressure of 20 cm. of water in the eye ball and this must be overcome if the small blood vessels (capillaries in the retina) are not to be collapsed by the internal pressure, as they will be if the effective blood pressure falls. The brain, however, is enclosed in the skull which resists pressure and although the blood pressure in its arteries falls, the finer blood vessels are not collapsed and consequently the eyes suffer before the brain.

The figures 16 and 17 are intended to show the importance of the difference in height between the heart and the brain and the effect of centrifugal force.

In figure 16 a series of heads are drawn at varying heights above the heart. The heights of the heads above the heart are proportional to the changes in centrifugal force, which is shown by the numbers below the hearts. The vertical lines running through the heads represent 160 cm. of water pressure; the part of this pressure lost before reaching the brain is represented by a thin double line; the part effective in driving the blood through the brain as a thick line. As the value of *g* increases from 1-5 the weight of the blood increases and this is represented by raising the heads which would have the same effect. We see that at 2 *g* the loss of pressure from the heart to the brain doubles, at 3 *g* it is threefold, etc., and that the amount of pressure available for driving the blood through eyes and brain decreases, so that at 4 *g* only 40 cm. is available, which is not adequate for vision.

The importance of the blood pressure at heart level and of the difference in height between heart and head, as affecting the resistance to the effects of centrifugal force, is evident, and can be illustrated by the following comparison.

In the basement of a building is a pump which produces a pressure at the pump of 16 m. of water pressure. Three metres above, on the first floor, a water pressure of 5 m. is required to give an adequate flow of water through the system at this level. Now this system is moved up to the second floor, then into the third and finally into the fourth, where the water pressure will be only 4 m. of water (16 m. less $4 \times 3 = 4$). With every floor the pressure available to force the water through the system becomes less. In order to produce an adequate flow through the system, either the pressure must be increased by $4+1=5$, or the system must be lowered by one floor.

The most important consideration for understanding the ability to withstand the effect of centrifugal forces, is that visual disturbances always occur when the blood pressure in the arteries of the brain falls below a certain value. This critical pressure is shown in our figures as 50 cm. of water.

In figure 17 we have a similar representation of the effects of centrifugal force. Again the blood pressure, 160 cm., is represented by vertical lines, thin double, that not effective in forcing blood through the brain; and thick, the effective pressure. Again the centrifugal forces are shown in multiples of *g* along the heart line. The critical pressure for visual disturbance is represented by the thick horizontal line. If we take the figure sitting upright, the decrease in effective pressure due to centrifugal force is shown by the heavy line, No. 2, slanting up to the right; it reaches the critical level at 3.75 *g*. Were this person to have a blood pressure of only 140 cm. instead of 160 cm., then the line representing the effect of centrifugal force would reach

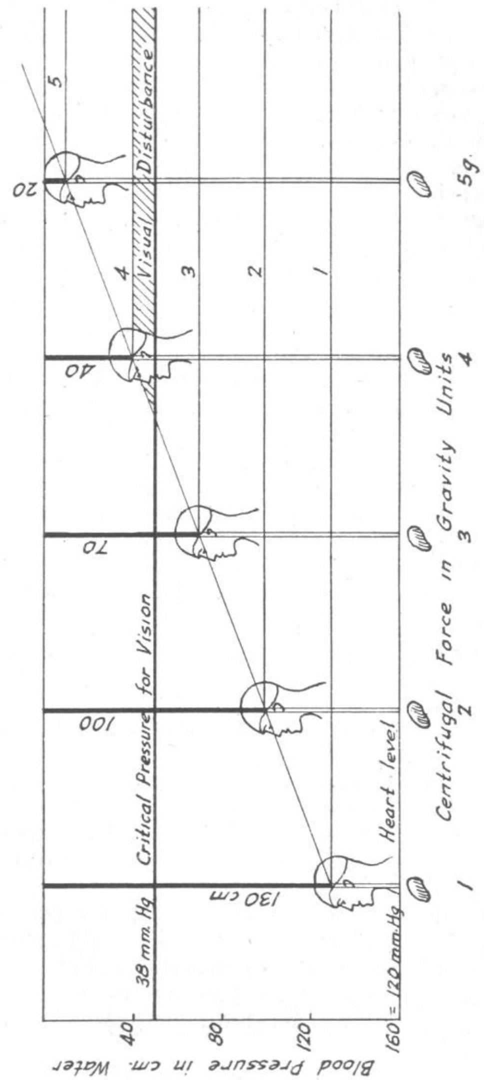

FIG. 16.—Described in text. The critical pressure required to give an adequate oxygen supply to the eyes is 38 mm. Hg., or 50 cm. of water.

the critical level at 3 *g* (short line No. 1), a loss of 0.75 *g*; while if the person had a pressure of 210 cm. which has been observed in men when flying, then the line representing the effect of centrifugal force would be No. 3, ending at 4 *g*, a gain of 1 *g* over normal. Now let us turn to the left-hand figure which is represented as bending forward so that his head is now only 20 cm. above the heart instead of 30 cm. He has available for driving the blood through the brain 140 cm. instead of 130 cm. The broken line, No. 4, represents the effect of centrifugal force and is seen to reach the critical level at 5.5 *g*, a gain of 1.75 as compared to line No. 2. Broken line No. 5 represents the case of a person bending forward with a blood pressure of 210, and it reaches the critical level at 8 *g*. It can be seen that every rise of blood pressure of 30 cm. in persons sitting upright, will theoretically decrease the liability to visual disturbances by 1 *g* of centrifugal force, while a fall of 30 cm. will lead to visual disturbances by 1 *g* less of force.

The same gain in the prevention of symptoms as by a rise of 30 cm. in blood pressure is produced by lowering the head by 10 cm. as occurs when bending forward. At a centrifugal force of 6 *g* the effect of bending forward would be theoretically 2 *g*.

This figure also shows us that the blood pressure in the lower parts of the body in a normal sitting posture is 30-40 cm. higher than at the heart.

Increases of blood pressure of 50 cm., such as are referred to above, occur, due to physiological and emotional influences, and this explains why centrifugal forces of even 7 *g* have been withstood for several seconds without symptoms, even by persons in the upright sitting position.

In older persons over 40 years of age we frequently find blood pressures at rest of 200-210 cm. water = 140-150 mm. Hg. Therefore older persons should on an average suffer less from centrifugal forces than younger ones, which in fact has been confirmed in practice and in experimental flights. Also the blood vessels of older persons are more rigid and consequently do not give way so easily and consequently there is a decrease of the pooling of the blood in the regions below the heart.

In this connection it is to be observed that in a person leaning forward the theoretical gain of resistance of 1 *g* is obtained by a rise of blood pressure of 20 cm., while for one sitting upright the pressure must rise 30 cm. Any rise of blood pressure has about 1 1/3 times the effect in a person bending forward as compared to one sitting upright.

In older persons it must, however, be remembered that not only may their vessels have become more rigid, but that their heart muscle

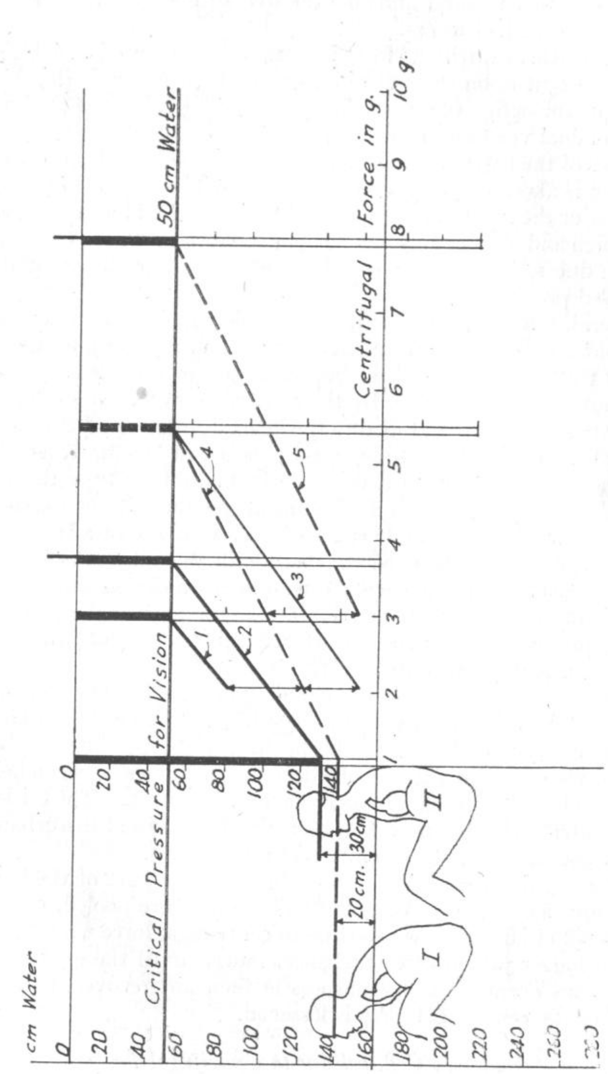

FIG. 17.—Described in text.

may no longer be as sound and may be overstrained by the stresses imposed by centrifugal forces.

Below the heart centrifugal force increases the pressure in the blood vessels, dependent upon their distance below the heart level (fig. 17). For example, the action of a centrifugal force of 5 *g* raises the pressure in the abdominal vessels of a sitting person to 240-260 cm. water, and in the calves of the leg of a standing person from 260 to 760 cm. water; this increase is about ¾ of an atmosphere. The higher blood pressure in the calves or the feet has been observed by fliers when the centrifugal force was high and occasionally small haemorrhages have been observed in the skin due to the smallest blood vessels having given way under the increased pressure.

In general, however, the blood vessels resist the increased internal pressure but the musculature in their walls relax and a considerable amount of the blood is pooled in the lower part of the body. If the body cannot offset this pooling by the constriction of vessels in other vascular areas, the return of blood to the heart decreases and the blood pressure falls. Every decrease in blood pressure of 30 cm. water in a man sitting, is equivalent to a decrease in his ability to withstand centrifugal force by 1 *g*. Therefore all measures that can be taken to prevent a fall of pressure, or better to increase it, are of advantage. For example, a properly applied contraction of the belly muscles will aid, only it must be properly carried out to increase the pressure in the belly and not to interfere with respiration, for any holding of the respiration produces a short rise, but then a fall of pressure, owing to a decreased return of blood to the heart.

In as far as any loss of vision or clouding of consciousness depends merely on the critical pressure for the blood flow through the eyes and brain produced by the height of the head, a slight bending forward will lead to vision clearing due to the decreased distance between head and heart and to the decreased loss of effective pressure. The critical effect of centrifugal force may be observed as the visual disturbance comes and goes with slight movements of the controls.

If, however, the great blood vessels in the lower part of the body give way sufficiently and large quantities of blood are pooled, we will have a case of circulatory collapse due to centrifugal force which leads to a much longer period of disturbance, indeed until the circulation again becomes normal. Consciousness is then not recovered immediately after the centrifugal force is lessened.

The Circulatory Collapse due to Centrifugal Force

This type of circulatory collapse resembles the fainting and loss of consciousness that may occur after long standing, particularly in a

hot, close room. In this case also the cause is the pooling of the blood in the lower part of the body with an insufficient return to the heart, which beats when inadequately filled and the brain vessels fail to receive blood under adequate pressure. But in flying such long-lasting unconsciousness due to a failure of the circulation seldom occurs because in flying the centrifugal forces only last a short time, less than 5 seconds, and in normal persons as a rule only centrifugal forces which last a much longer time are required to produce such a pooling as will produce a dangerous fall in blood pressure. But after a wakeful night, particularly when there has been too much smoking and/or drinking, or just after recovery from an infectious disease (influenza, tonsilitis, etc.) the resistance of the vascular system may be so reduced that even a comparatively slight centrifugal force (of 4.5 *g*) and lasting a short time (less than 3 seconds) may cause severe unconsciousness. This danger may be considerably increased by the effect of altitude and by inhaling exhaust gas.

Naturally, long-lasting unconsciousness is very dangerous if the pilot is affected. Persons who show a tendency for their vessels to give and to fainting, are therefore not suitable as personnel for high power aeroplanes.

What is the Limit of the Bearable Centrifugal Force and How Can We Best Resist High Centrifugal Force

According to our theoretical discussion, the limit of the bearable without symptoms, when sitting upright, must lie between 3.75 *g* and 5.5, or when bent over between 5.5-8 *g*.

The most favourable position for resisting centrifugal force is naturally lying down, because then the differences in blood pressure are naturally less. The loss of pressure between heart and head is very slight and the increase in the belly and legs is equally so. The latter, when sitting, could in part be prevented by lifting the legs, which is accomplished by the high level of the rudder bar in some aeroplanes.

In a person lying on his back the centrifugal force acts in the direction from breast to back. Experiments with the centrifuge in the Air Research Institute have shown that a force of 15 *g* can be borne for 30 seconds. However, respiration with the chest muscles became almost impossible at over 10 *g*, because the chest could not be lifted against the centrifugal force.

This theoretical discussion is supported by the observations made on 22 persons (¾ of them not experienced fliers) during 100 experimental flights. In fig. 18 we see that all persons, 100%, have withstood a centrifugal force of 4 *g* for 3 seconds without disturbance of vision, that about 50% had visual disturbances above 6 *g* and lost consciousness at 7 *g*. No person withstood 8 *g* when sitting upright. These results suggest that most of these persons had an increased blood pressure during the centrifugal force, as otherwise 6 *g* could not have been withstood by them when sitting upright.

On the evidence in the literature it may be assumed that probably in a larger series of experiments the limits at which visual disturbances would occur in persons sitting upright would lie somewhat lower and would be found at about 5-6 *g*. By bending forward, as shown in fig. 17, the limit without symptoms could be increased by 2 *g* of centrifugal force.

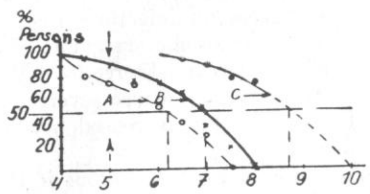

FIG. 18.—Curves showing the effects of centrifugal force on 22 men in 100 tests. The average number of persons not affected are scaled in percentage on the left, the centrifugal forces on the base. Line A. . . . beginning of visual defects. Line B——loss of vision. Line C when bent forward.

Although only experiments with a force up to 8 *g* have been carried out because the strength of the experimental machine would not allow of a higher strain, it can be assumed with great probability that persons who when sitting upright can withstand 8 *g* without loss of vision would, when bent forward, have withstood 10 *g* for five seconds. Some highly resistant persons when bent forward may perhaps be able to withstand 10 *g* for several seconds.

The experiments showed also that very tall, slender persons were less resistant to centrifugal force. They often had a low blood pressure and a tendency to circulatory collapse. A low resistance is also shown by young athletes in the height of training and particularly those overtrained, because in this condition they have a hypersensitive circulatory system.

The people who best withstand centrifugal force are the small, solid type, especially as they, during the centrifugal force, tend to have a rise of blood pressure.

Therefore the question—are we today, or will we be in the near future, in a position to resist the centrifugal forces of the modern fighter and power diving aeroplanes? This we can answer positively if we place the stress that has to be borne as 8 *g* lasting for 5 seconds, since without exception even the sensitive, tall, slender persons and those showing a

tendency to circulatory failure could withstand this force without symptoms when bent forward.

If it should become necessary in the future to resist even a higher centrifugal force than 8 *g* for several seconds, lying on the back would greatly increase the resistance. Whether it would be advisable to make it possible for the fliers of such machines to resist greater centrifugal forces by lying on their backs with the aid of a tilting seat, requires a great deal of further investigation and experiment, since in a flight in the air in which a failure for a second on the part of the pilot might be decisive, the most intense concentration of all fighting energy is necessary, and if during an aerial combat the pilot loses sight of the opponent for an instant he is often lost. In a hot and heavy fight for life or death, a position on the back would be physically and in its effect on the fighting spirit much more unfavourable than a proper tense position crouching forwards. The field of vision is also considerably decreased when lying on the back.

A man is instinctively drawn to crouch forward by the physical and emotional strain of fighting. Even if it should later be found that a tilted-on-the-back position would be more favourable in practice in aiding in the resistance to centrifugal force, we have to deal with the present arrangements and aid ourselves as much as may be by bending forward.

The advantages of crouching forward under centrifugal force as compared to sitting upright are due to the following causes:

(*a*) The lowering of the head at least 10 cm. (4 inches) produces a gain in resistance of 3 *g* on a centrifugal force of 9 *g*;

(*b*) The pressing in of the belly that this entails tends to prevent the pooling of the blood and a fall of blood pressure or may even cause a rise;

(*c*) This position of crouching to attack has a psychological effect and due to this there may be a secondary effect on the vascular system leading to an increase in blood pressure and resistance.

The prone position (lying on the belly) which is employed today by machine gunners and others, is disadvantageous for the resistance of centrifugal force because the body lies on the chest and belly which entails considerable effort in breathing and because there is difficulty even during normal flight in holding the head up. This position requires, therefore, the provision of special supporting pillows to take the load off the chest and muscles of the neck.

The limits of what can be withstood in this position are as yet unknown and their investigation is certainly not without risk, because the organs in the chest and belly have no longer their natural support and may pull upon their attachments.

Under certain circumstances lying on the side may allow persons to withstand centrifugal forces better than on the belly. If very high centrifugal forces are to be expected, it is advantageous to turn from the belly position to the side or back.

The pursuit or dive bomber pilot can make crouching forward in part automatic by arranging his seat high, so that he has to lean forward in order to keep his objective in the sights. When the centrifugal force arises he is automatically forced into the bending forward position.

FIG. 19.—The crouched forward position.

Transitory Visual Disturbances and Slight Defects in Consciousness after Abrupt Zooming

Crouching forward is also advantageous in the case of another form of disturbance of vision and consciousness, which at times has been experienced by fliers after centrifugal force that has been rapid in onset and disappearance and which consists in a slight clouding of consciousness with a short period of disorientation in regard to the position of the aeroplane in space.

A pilot has been known to suffer from such a disturbance when zooming his aeroplane abruptly out of a horizontal flight, to avoid

his opponent attacking unexpectedly from below. This action resulted in a collision with another aeroplane of his own squadron.

Such disturbances, which may occur with even comparatively small centrifugal forces such as 4 *g*, are particularly dangerous after abrupt ascents of the aeroplane from close to the ground, because the correct time at which to change to the horizontal may be missed, and under certain circumstances may lead to a stall and loss of control, resulting in a serious crash.

Again, this type of disturbance is very dangerous when aeroplanes are exercising in close formation. It is apparent that fliers who show a tendency to such disturbances, and cannot prevent them by crouching forward, are unsuited as combat pilots.

The cause of this type of disturbance is not as yet explained. (It suffices for the pilot to know that it may occur with relatively small centrifugal forces, and that the pilot can definitely combat it by crouching forward.)

[It is possible that the rapidly occurring increase of centrifugal force at once leads to a pooling of a considerable amount of blood in the vessels below the heart which suddenly dilate (the latest Roentgen-ray pictures taken during flight suggest this also) and before the regulatory influences are able to produce a compensatory constriction of the vessels the centrifugal force ceases. The sudden reduction of centrifugal force and its decrease of vascular stress act as a powerful stimulus to the regulatory centres and through the nerves cause for a few seconds a further fall of pressure so that eyes and brain for a few seconds are inadequately supplied with blood. Perhaps there is some other explanation, but the disturbance is certainly due to a very transitory disturbance of the circulation to the eyes and brain.]

The possibility of a concussion of the brain must also be considered in the case of extremely rapid and great changes in centrifugal force. (What forces would be necessary are not adequately known.) But certainly such forces lie beyond the strength of the present aeroplanes and hence are of no practical importance.

The Effect of Centrifugal Force When Flying Upside Down

While in normal flight, transitory disturbances of vision and consciousness may occur, owing to high centrifugal forces when sitting or lying on the back; no permanent effects have been described in healthy persons. When flying upside down, however, longer-lasting defects in health may be produced. When upside down the weight of the blood column throughout the body presses on the vessels of the brain and may therefore greatly increase the blood pressure in the eyes, and centrifugal force will increase the pressure.

In this case a centrifugal force of 5 *g* will increase the blood pressure in the arteries of the brain to about 500 cm. water as compared to the normal pressure of 120-150, i.e. to more than three times. While normal vessels can readily withstand such a pressure, this is not true for diseased vessels, such as may occur in older persons. Persons over 45 are to be considered as endangered by flying upside down. Naturally the blood pressure in the eyes also increases and the capillaries in the whites of the eyes are the least resistant. It is known that they may be ruptured by a comparatively slight rise in pressure such as occurs when straining at stool. Such bleeding in the whites of the eyes have occurred during trick flying upside down. These bleedings are relatively harmless and disappear in a few weeks completely. But if the centrifugal force when upside down surpasses 4 *g*, there arises the danger that bleedings may occur in the retina, which may lead to blindness. Hence inverted turns should be carried out as gently as possible and forces of 3 *g* are to be exceeded only exceptionally and those of 4 *g* never.

Again, when upside down a comparatively low centrifugal force may lead to severe headache in consequence of the increased blood pressure in the brain. Vision disappears with forces of hardly 4 *g* in consequence of the increase in pressure within the eyeball and seeing "red" may first occur, due to the over-filling of the blood vessels.

The visual disturbances when flying upside down outlast the stress for several seconds. For this reason the former master acrobat flier, Fieseler, always carried out his inverted turns as "gently" as possible, as otherwise his vision was disturbed for some time and he got a headache which lasted frequently for several hours.

[Acrobatic fliers who must resist centrifugal forces of more than 4 *g* in order to break a record, for example, must re-arrange their seat so that they fly either prone or recumbent so that they can withstand such forces as long as they like.]

General Remarks

In order to resist high centrifugal forces it is very important not to fly with an empty stomach, particularly if the flier has had a sleepless night, as this decreases the resistance of the vascular system so that relatively small centrifugal forces may lead to a more severe and longer loss of consciousness. On the other hand, it is not advisable to have eaten an excessive meal shortly before flying.

The combination of sleeplessness, alcohol, and excessive smoking

has a most deleterious effect on the resistance. Any one who flies with an empty stomach after a night's celebration is a "criminal," because he must count on a decrease in his attention and ability to react and also under normal flying stress may expect to be unwell and to faint.

Diseases with fever and digestive disturbances decrease considerably the resistance to centrifugal forces and to altitude sickness, as mentioned before. Such a decrease in resistance may last for 3-4 weeks after recovery from "la grippe," as the circulation often returns only slowly to normal. In such cases there is a danger of circulatory collapse with long-lasting unconsciousness. Consequently great caution is necessary after the recovery from "la grippe" or other infectious fevers.

If the effects of altitude and of centrifugal forces combine, they mutually increase each other's actions. Consequently for this reason also it is necessary to use the oxygen supply above 4,500 m., 15,000 ft., since the additional effect of centrifugal force at over 5,000 m., 16,400 ft., may easily lead to such a loss of consciousness that the aeroplane would crash.

D. THE IMPORTANCE OF THE SENSE ORGANS FOR THE FLIER

1. The Eyes

The most important sense organ for the flier is his eyes. Like an eagle he must spy out his objective from great heights and must recognize his opponent as soon as possible. Therefore every flier who can improve his vision by the use of glasses should make use of them and should at once become accustomed to using them when flying. (Many persons who do not wear spectacles because their vision is adequate and have passed the examination for fliers, can increase their vision 50% by glasses.) Good vision is particularly important in estimating the possibility of landing in unprepared fields.

When flying in sight of the earth, particularly in trick flying, the eye is the most important organ for the orientation in space for it acts as a natural measure of bank, of pitch, of direction, and in changes of direction it measures the speed of the turn. In a "blind flight," paradoxical as it may seem, it is the only organ which can give a correct objective estimation of the position in space, and the condition of the flight, because it enables the observation of the instruments. It may, however, even in a flight without a view of the earth, produce an entirely false estimation (optical illusion) of position and movement due to the control by the organ of equilibrium of the muscles which move the eyeball.

If from the other sense organs impressions of the position are given, which differ from those given by the eyes, as for example in turning when the resultant of gravity and centrifugal force leads to a deceptive judgment of the vertical plane, it is the eye and the intelligence which decide on the true vertical and the horizontal planes in regard to the surface of the earth.

From the eyes which are so important for equilibrium, impulses may be sent through the central mechanism to the muscles, which lead to their making undesirable movements and produce dizziness. For this reason many persons when looking down, or occasionally ones when looking up a steep wall, become dizzy.

This "optical" dizziness is produced because the eyes, as their share of the control of equilibrium, try to keep the body always upright by putting into activity the appropriate muscles, or what is the same thing, those to keep the longitudinal axis of the body parallel to the force of gravity.

On looking down a long wall without a railing, the wall acts on the eyes as a horizontal surface and there arise, particularly in persons who are sensitive to this condition, an involuntary increase in muscle tension, particularly in the legs, which presses the body forwards. This produces a mysterious anxiety that one must topple forwards. And to this is added the anxiety attendant on the idea of falling over. If there is a railing on the wall with vertical supports, these aid the eye in judging what is vertical and therefore the position of the horizon. The railing in itself diminishes the share produced purely mentally in this complex of dizziness.

In the aeroplane and in a free balloon the eye, when looking downwards, finds no vertical surface and consequently does not induce this type of dizziness. For this reason many persons who become dizzy in looking down from a wall have no dizziness when looking from a high bridge into calm water or to the earth.

The eyes as the most important sense organ for the flier should be particularly protected from injury. Goggles protect against the wind. They must be a good fit and must particularly close off the inner angles of the eyes so that the air current may not damage the outer surface of the eyeball and lead to a chronic inflammation of the surface, which often resists medical treatment stubbornly. Such a chronic inflammation is frequently the cause of an early fatigue when reading and makes remaining in a room full of smoke a torture.

If the eyes are sensitive or have been irritated, it is advisable to rub with a glass rod some boric acid salve on the edges of the lower lids and particularly in the inner angles, morning and evening. This

means of protection is also advisable for a motor trip, particularly if the air is dry and dusty.

Anyone who is sensitive to bright light (and most of these persons have a chronic inflammation) may wear in his flying goggles coloured glasses. These glasses absorb particularly the bright yellow light and allow the contrast between red and green to appear more distinctly. Also they improve the vision particularly in bright steamy weather. They are therefore particularly advisable for naval fliers.

Damage to the eyes through brightness, like snow blindness, is only to be feared after long flying in bright moist air or over bright clouds. In bright, clear air without any reflection from clouds or snow surfaces, the occurrence of blindness is relatively very infrequent.

The colour blind, mostly red-green blind, are not improved by coloured glasses. They distinguish colours in ordinary life by their brightness. If red and green have the same brightness they fail to distinguish them.

As long as in aerial navigation the distinguishing lights red and green are employed, fliers must be required to distinguish colours with certainty and since experience has shown that only slightly colour blind persons may under certain conditions of lighting confuse red, green, and white and that any uncertainty in colour vision increases with fatigue and is greatly increased by oxygen lack, only persons with full colour vision should be entrusted with an aeroplane.

In flying goggles a glass is often used which is coloured only in its upper part. They are particularly comfortable when flying towards a low sun and make easier the recognition of an opponent attacking from the sun's direction. Also in landing in the late evening twilight the adaptation of the eye to the darkness on the ground is made easier if the bright horizon is darkened by the coloured part of the glass. In this way the sensitivity of the eyes to the light in landing may be considerably increased.

In flying towards a difficult landing in the twilight it is not advisable to look at the horizon in order to enjoy the beauties of the sunset, but it is advisable to look at the dark earth in order to accommodate the eye to the darkness.

The danger of being blinded by searchlights and losing control of the aeroplane is not great for a flier experienced in the use of his instruments, provided he is not forced to avoid the searchlight by turning steeply. The flying of steep turns in a cone of searchlights is amongst the greatest achievements of the flier, for in this case the instruments for blind flying are not sufficient guide.

2. The Ear

The ear functions as (*a*) the organ of hearing and (*b*) an organ of equilibrium.

(*a*) The Ear as the Organ of Hearing

As an organ of hearing the ear serves as a control on the running of the engines and is aided in this respect by the vibration sensitivity of the skin. In many types of aeroplanes the noise produced in flight may well be used for the finer control of speed because the ear is able to recognize every change of the pitch and the character of sounds. In landing many fliers either consciously or unconsciously employ the noise of the flight to estimate the flying speed shortly before settling on the ground. It is therefore important when landing from greater heights to adjust the air pressure in the middle ear by forcing air into it by compressing the cheeks with mouth and nose closed, as otherwise hearing is seriously impaired by the undue external pressure on the drum and mistakes in judging the speed by the noise may easily occur. If the pressure in the middle ear has not been equalized with that in the surrounding air at greater heights the sound of the flight may be weakened and give the false impression of a decrease in speed. This is one of the causes of bad landings after high flights. Another cause is a rather long-lasting disturbance following oxygen lack, which leads to stereoscopic vision (the appreciation of depth) and consequently the visual estimation of speed being below normal.

The perception of changes in sound is particularly important for the glider in helping him to maintain his height in rapidly changing strengths of the wind, because these sound changes enable him to do so without watching his flight indicator constantly.

It should, however, be noted that the sound of flight is louder when flying in clouds and this may deceive by suggesting an increase in speed.

In hearing, the vibrations in the air produced by noise are collected by the ear proper and conducted through the external ear passage to the drum, which in turn vibrates. These vibrations are transmitted by the bones of the middle ear to the fluid in the cochlea in the inner ear (fig. 4). In the cochlea are found the endings of the nerves of hearing (the so-called organ of Corti). Their stimulation by the vibrations are sensed by the brain as musical tones or noises.

On account of the increasing importance of radio communication between the aeroplane and the ground, the hearing capacity of flying personnel must be adequate for faultless telephonic communication.

(*b*) The Ear as an Organ of Equilibrium

On the ground a man with his eyes shut determines his position in relation to the force of gravity, whose direction is detected by the nerves which respond to pressure on the skin, and to those which respond to tension and weight in the muscles and joints and particularly those of the organ of equilibrium in the ear.

This organ for equilibrium control consists of:

1. The "static organ" for the perception of the direction of gravity at any moment and probably also of acceleration in any plane;
2. The semicircular canals which respond to movements of rotation (change of direction).

The chief duty of this organ is not the transmission of sensations to the brain but, aided by the nerves from skin, muscles, and joints, to control the movements of the muscles in order to maintain the equilibrium in every position of the body and during all its movements and also to control the muscles of the eyeballs so that while the body turns things in space may be perceived as if they stood still and orientation in space is maintained.

This control of the eyes we can feel on ourselves if we shut our eyes and put a finger lightly on the eyeball and turn round. Then we feel the little twitches of the eye (nystagmus) which have a slow phase opposite to the turning movement and a fast phase in its direction. Owing to these twitchings if the eyes are opened what we see in turning is presented as a series of momentary pictures like a cinema film.

This organ of equilibrium, together with the eyes, form the controlling mechanism for the maintenance of human equilibrium. They are united closely with each other by nerve paths and this connection is the source of many false conceptions, particularly in a blind flight, because the ear apparatus is not able to distinguish between gravity with which it normally deals and centrifugal force, and reacts, as a matter of fact, to the resultant of these two forces. The eyes are controlled in part by what they see and in part by the nerve impulses from the ears.

Consequently it frequently happens that in flying the sensations sent by the ear are in opposition to those sent by the other sensory organs. The central mechanism for the maintenance of equilibrium may therefore receive contradictory nervous impulses and these confused and contradictory directions to the body are the chief cause of air sickness as of sea sickness.

Consequently persons with insensitive organs of equilibrium often tend to be less sick in the air and at sea because in them the opposition between these two controls of equilibrium is less likely to occur.

Most people can by practice adapt themselves to the conditions arising from movements in space, their reactions to these opposing influences become less, and consequently they become more resistant to air and sea sickness.

In this connection a visit to the "witches' house," often displayed in pleasure resorts, in which the visitor experiences at the same time

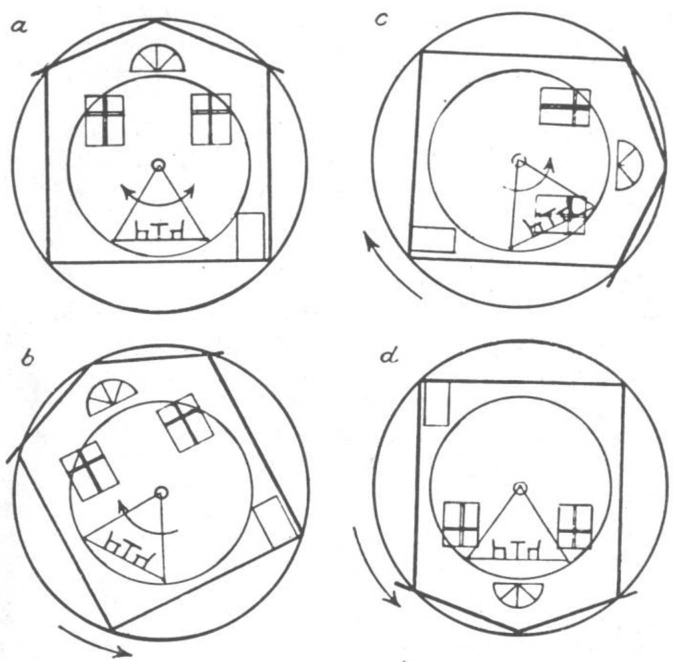

FIG. 20.—Plan of the Witches' House described in text.

false sensations from the eyes and the organ of equilibrium, is informative. The deception arises from the inadequate perception of the extent of the swings of the pendulums in space. Consequently the optical illusion may be so great as to suggest that one is standing on one's head and the confusion of sensations from the eyes and the organ of equilibrium produces in most persons nausea and vomiting (fig. 20).

Explanation of the Figure—Plan of the Witches' House

(*a*) The floor and the house (walls) are suspended on the same axle but can be turned independently. Sitting on the chairs on the floor when the pendulum (of which the floor is part) is set swinging, one senses both by general sensations and the eyes, the pendular movement quite accurately. (*b*) After a few pendular movements the house is caused to swing, but in the opposite direction. As one cannot see out of the house, therefore one does not realize that the house has begun to move and one thinks that the first swinging movement has increased. (*c*) While the swinging of the floor remains the same, that of the house is caused to increase. One is deceived, believes one's

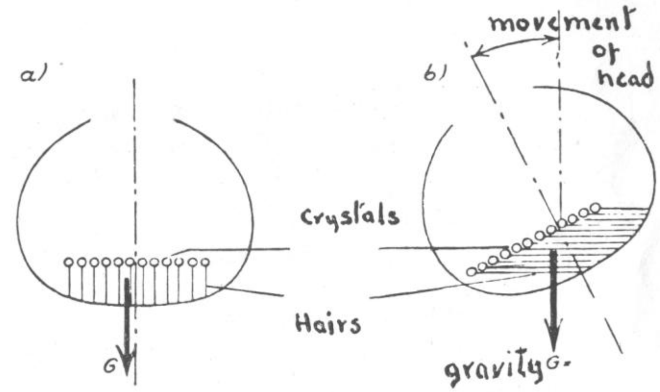

FIG. 21.—Diagram to indicate how the "static organ" in the ear is affected by changes in the position of the head.

eyes, and begins to hold fast. (*d*) When the condition illustrated in *d* is reached, one pictures oneself as hanging helpless upside down. The confusion between the sensations received from the eyes, and from the skin and ear, produces sickness and vomiting.

The "static organ" is found in two small bays in the inner ear, which have on their bottoms a membrane of sensory hairs on which rest small chalk crystals (the otoliths) imbedded in mucus (Fig. 21).

To every change in the position of the head, as compared with the direction of gravity, corresponding changes occur in the load borne by this sensory membrane. If the head is held obliquely (to one side) the sensory hairs are called into play towards one side and transmit this information by their nerves to the centre controlling equilibrium and the brain, which also receives through the nerves from the muscles that have contracted, and their tendons, news of these changes. The mode of action of this static organ is comparable to a water level.

If in flight the force of gravity and centrifugal force come into play, it is the resultant of these forces which is sensed by the position of the otoliths and in flying without the aid of sight may deceive the flier as to his position in space.

In the beginner in flying this deception of the senses may lead during a turn, even when in sight of the earth, to the feeling that the aeroplane is level and the ground inclines. This deception may occur and last for a few seconds even in experienced fliers when they have just broken through a cloud bank.

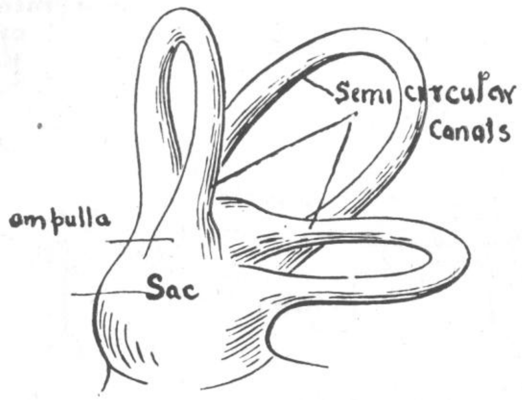

FIG. 22.—Diagram of the semicircular canals. Each canal lies in a plane at right angles to the others. One curves upward and vertical, one forward and vertical, and the third horizontally.

Man senses turning movements by means of the semicircular canals which are full of fluid. They are particularly well developed in birds and in fish which must move in three directions in space.

These semicircular canals are three in number in each ear. These lie at right angles to each other and all end in a common sac. In little bays (ampullae) at the end of each canal there are little sensory hairs which project into the fluid which fills it. These are the sensory organs which respond to the movement of turning.

If the body, and hence the head, is rotated, the fluid in the canal of the plane in which the rotation is carried out does not move on

account of its inertia as rapidly as the rotation of the body. Consequently a steaming movement occurs in the opposite direction to the rotation. This bends the sensory hairs in the ampulla. This stimulation is conveyed by the nerves to the centre for equilibrium and to the brain and finally the cerebral cortex is made conscious of the movement (fig. 23).

The sensation of turning occurs only during a change in rate of a turning movement that is at the beginning and ending and only when the turning movement exceeds a certain limit ($\pm$ 2° per second). If the rate is less, the fluid is moved equally with the movement and no

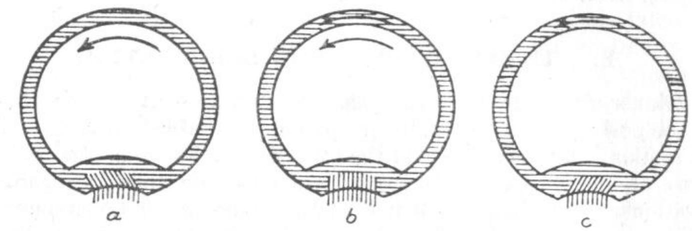

FIG. 23.—Diagram to show the action of one semicircular canal.
a.—At the commencement of a rotation to the left in the plane of this canal, the fluid does not move as soon as the canal does and the sensory hairs are bent to the left. One senses a turning to the left.
b.—The rotation continues at the same speed, the fluid now is moving as rapidly as the canal, the hairs are upright and no turning movement is felt.
c.—The rotation has ceased, the fluid continues to move in the same direction for a time and so bends the hairs in the opposite direction. The sensation is that of turning to the right.

sensation of turning is produced. It is therefore possible to rotate a person at a slowly increasing rate without his being aware of it. This is of practical importance in a blind flight because the aeroplane may turn slowly out of course without its being noticed.

If the acceleration due to turning passes over into an even turning movement, the fluid in the canals gradually takes on the rate of the canals themselves. The sensory hairs take their normal position and the sensation of turning ceases.

If a negative acceleration be now brought into action, a decrease of speed, the fluid in the canals continues at first to flow, the hairs are bent in the opposite direction, and the sensation is created of being turned in the opposite direction. This turning does not in fact occur; it is a deception.

If a man has his eyes shut, he has no means of sensing a uniform turning movement but can only sense acceleration or deceleration of a turning movement. This can be easily tested on a noiseless turn-table such as is used in the examination of flying personnel.

A movement of the head while turning produces movements of the fluids in the canals which may differ markedly from those produced by the head movement alone, and there arise additional sensations which in rapid spin at a high rate of rotation may be falsely sensed as tipping over.

E. SENSORY ILLUSIONS IN BLIND FLYING

Man's sense organs are no longer adequate to orient him in regard to the position of his aeroplane in space or to enable him to recognize its motion if he has no view of the earth or of a horizon. Indeed, his sense organs are frequently a source of false sensations in regard to position and motion, which in certain circumstances on account of their convincing quality shake his belief in his instruments and hence endanger the safety of his flight.

The chief reasons for this are:

1. That the human mechanism for equilibrium cannot, when a turn is made in the air, distinguish between centrifugal force and gravity because these forces are fused as the resultant whose direction in relation to the earth's surface cannot be recognized if no horizon is in sight.
2. That the organs of equilibrium sense only changes in speed and not uniform velocities. This is true both for motions in a straight line and in curves. Further, changes in speed are sensed only if the acceleration exceeds a certain amount per second.

Therefore the blind flier is dependent on his instruments—turn indicator (plummet) and rate of climb indicator—which must replace for him his loss of sight, by other indications of the position and motion of his machine, and in this his other instruments—the alimeter, the artificial horizon, the revolution indicator, and the air speed indicator—have an increased importance for the maintenance of any desired flight.

Since a flier confined to the use of his senses alone after even a short flight out of sight of the earth or a horizon soon loses knowledge of his position in space, flying in the clouds without perfect blind flying instruments is forbidden.

In the training of a blind flier, or more properly of a flier by the aid of instruments alone, he must disregard above all else the sensations which indicate position and movement, or at least put them into the background of his mind.

This is often much more easily learned by the inexperienced pupil pilot than by a fully experienced one who has developed a marked "flying sense." This in the true sense of the word has developed on a broader basis with the pilot who feels himself to be part of the aeroplane and has made out of his ship a new sense organ in order that he may fly as freely as possible without watching his instruments.

While formerly the development of this "flying sense" was decisive for his ability as a pilot and still holds its full importance in landing, in acrobatic flights, and also during a flight in spirals, it must be largely put aside for blind flying. It must be replaced by logical thinking.

In blind flying the pilot must free himself entirely from the desire to direct his flight by his own instinct. He must endeavour to direct his course by the instruments and hold it in this position. That is to say, he must not fly his aeroplane but his instruments. This requires the development of a fine feeling for the necessary changes in manipulation that must be cut free from the developed "flying sense," which in a blind flight is so often deceptive, and to this fine feeling the sensation of force and position in the arms and legs during flying plays an important role.

The following disturbing deceptions of sensation in regard to the position and movement of the aeroplane may be produced during blind flying through the faulty operation of the human equilibrium mechanism.

1. The feeling of ascent whilst turning;
2. The feeling of sinking on recovering from a turn;
3. The feeling of a tilt to the opposite side during a turn;
4. A feeling of tilting when flying between two cloud banks of different slope (sloping towards each other);
5. A feeling of turning during an even flight;
6. The feeling, due to movements of the head, that the aeroplane is tipping during too sharp a turn.

These illusions arise from the sensations proceeding from the organs of equilibrium which produce false ideas of the position in space and of the motion which often have a convincing distinctness, because the position of the eyeballs is controlled by the mechanism for equilibrium and owing to their forced motion convey illusions in regard to the motion of the aeroplane.

(1) In carrying out an unnecessarily steep turn in blind flight the additional strain on the body due to the centrifugal force may produce

the sensation of ascent. The angle of bank of the aeroplane is sensed as a position of ascent, and also seen as such (see p. 53). This sensation gradually disappears if the turn is maintained constant for a longer time.

(2) The change to a level flight from an unnecessarily steep turn may lead to a feeling of less than normal weight owing to the removal of centrifugal force and hence a feeling that the aeroplane is sinking. This feeling is the more marked the greater the stress produced by the centrifugal force. The removal of the stress after a long-continued action of a centrifugal force, for example when flying in a close spiral, may lead to a very disagreeable feeling of falling even when the flight has been carried out with the earth in sight and the aeroplane has finally been levelled out of the spiral. This feeling may be so marked that only observing the instruments and cold logical thinking will remove the illusion.

If an excessively steep turn flown blind has ended, the reduction of the angle of bank may be sensed as a "pressure" and the position of the aeroplane may be regarded as definitely that of losing height, although the plane is in reality flying horizontally because the impulses proceeding from the centre of equilibrium to the eyes have caused them to turn. If the pilot in the clouds depends solely on his sensations and trusts to his "flying sense" without looking at his instruments he will usually tend to underrate the steepness of his turns and consequently turn too steeply. On straightening out to horizontal flying he will have the tendency to over-correct the aeroplane if the change in the angle of the aeroplane leads him to believe that he is descending or he will ease back the control column if the sensation of falling seems to him to be stronger.

(3) In a perfect turn, when the ground or the horizon cannot be seen, the angle of tilt cannot be sensed because the resultant of gravity and centrifugal force must fall at right angles to the transverse axis. In blind flying the deviation of the resultant and with it of the ball of the turn indicator may be sensed as an inclination of the aeroplane to the side of the deviation.

If in a blind flight the aeroplane skids during a turn on account of its not having been given adequate bank, then the resultant no longer falls at right angles to the transverse axis. Then the sensation is that of a tilt of the aeroplane opposed to the true one. These sensory illusions in regard to the transverse plane may even arise in a blind flight flown absolutely in accordance with the instruction, because during training in blind flying it is taught to keep the ball of the turn indicator rather to the outside of the centre in order that a loss of

height due to slipping in may be avoided. In place of this loss it is better to have a slight skid outwards.

(4) The sensation of the aeroplane being tilted when flying between two layers of cloud which are inclined to the horizontal and with no visible horizon is at times so convincing that the flier begins to have doubts of the accuracy of his indicator and must by hard thinking overcome this false appreciation of the attitude of his aeroplane.

The cause of this illusion is due to the eyes having such an important role in the estimation of position, because the sloping cloud layers are regarded as a horizon.

(5) The most disturbing effect in blind flying is the sensation of turning which deviates from the truth, which occurs even during flying horizontally or during the most perfect turn and may produce the illusion of rotation about all three axes. This illusion of rotation is particularly convincing in blind flying because of the working together of the eyes with the organ of equilibrium in the ear which is failing to give the correct picture, thus leading to the impression of turning being not only felt but seen.

This is probably the most important contribution to the explanation of the astonishing and suddenly occurring dizziness of the pilot during blind flying.

Such illusions of turning arise especially on account of the numberless small disturbances of the aeroplane about its three axes, particularly when the flight is made in bumpy air or with an unstable aeroplane. All the accompanying sensations are worked up by the inner ear to produce false and disturbing sensations of rotation.

In part these rotations are sensed and in part they do not come to consciousness. As the sensations of turning which are sensed overlap each other and after sensations are added, finally an estimation of the movements is made which is quite false.

Such illusions of rotation may also arise when the aeroplane is in horizontal flight, for example when on account of airscrew torque the plane deviates slowly and unnoticed from its course and is then pulled back again by small movements of the rudder.

[The physiological cause for these illusions lies in the currents in the fluid of the seimicircular canals of the ear. The fluid during the slow phase of turning is carried with the movement of the canals themselves but in the fast phase (when the correction is made) the fluid lags behind the movement on account of its inertia. The sensory hairs are thus affected only by the movement in one direction and thus set up the sensation of a continuous rotation.]

(6) Finally, during a blind flight and an unduly sharp turn, a movement of the head leads to the illusory feeling that the aeroplane

is diving. Apart from the differences in individuals the strength of this feeling is directly dependent on the speed at which the turn is made and the rapidity of the movement of the head.

In turning with very high speed, e.g. in a spin, this sensation of tipping may occur distinctly even when the ground is in sight. During a tight spin with a turning speed of 1½ seconds per revolution even the movement of the head to read a low-placed instrument may produce the sensation of a going over the vertical so distinctly that the pilot involuntarily pulls on the control column which may lead, in certain circumstances, to a dangerous prolongation of the spin. Consequently it is advisable to hold the head very still during a fast spin.

In carrying out a turn in accordance with the regulations during blind flying, the turning speed of the aeroplane is so low that only particularly sensitive persons have such a tipping sensation even when carrying out an extensive movement of the head. But if the bank leads to a faster turn than that perceived, the false sensations engendered may lead to incorrect manipulation of the controls.

Consequently in blind flying only turns in accordance with the regulations should be carried out (i.e., 360° of angle in 3 min. or 6° per second).

If during blind flying the sensations are opposed to the instruments, the flier should take to heart the instructions for blind flying, "the sensations may deceive but the instruments tell the truth."

F. THE EFFECTS OF NOISE AND VIBRATION AND THE CAUSE OF AIR SICKNESS

It is known that long-lasting noises may lead to a permanent damage to hearing. Such damage due to noise has often been produced in animal experiments and can be demonstrated in microscopic sections of the cochlea of the internal ear.

Therefore many persons who have been constantly employed in the flying service suffer from a moderate decrease in hearing, especially for high tones due to the long-continued noises of the exhaust and the propeller. To avoid this it is recommended that the personnel of machines whose exhaust is not muffled should close their external ear passage with greased absorbent cotton. Also loud noises produce bodily and mental fatigue, because the tension of all muscles and of the centres of the nervous system is increased. We can observe this in ourselves particularly in our faces, since loud shrill noises will lead the facial muscles to contract involuntarily in a spasmodic fashion.

The ability to watch over the running of the motor is not decreased by the insertion of the cotton, but rather is increased after a short

period of getting used to the decrease in the loudness of the noise. Well-applied head receivers are also a good protection against the exhaust and propeller noises.

The same fatiguing effect as loud noises is also produced by those vibrations which lie too low to be sensed as sound, because they produce the increased muscular tension and are also directly fatiguing to the central nervous system.

In order to keep the personnel of an aeroplane during a flight of many hours as fresh as possible, it is advisable to dampen the noise of the exhaust and propeller and the vibration due to the motor as much as possible. Countless observations in the motor car and aeroplane have proved that the extent of fatigue during long trips depends essentially on the loudness of the noise and the amount of vibration.

The multiple changes in acceleration upwards and downwards and the irregular swaying of the aeroplane when flying through disturbed air are very frequent causes of fatigue and of a diminution of the sense of bodily well being. It is the most important cause of air sickness.

Air sickness has nothing to do with altitude sickness or lack of oxygen, but arises essentially, as does seasickness, due to the overstimulation of the human mechanism for equilibrium by the repeated up and down movements (the pitching as it is termed at sea), particularly when these are combined with rolling and side to side slipping. There arises a confusion in the mechanism for equilibrium leading to overstimulation of its centre and to spreading of the stimulation to other centres such as that for vomiting. But, varying very much with the individual, other nervous centres are also stimulated; for example, the centre that controls the tension in the muscles of the arteries and at times the pressure in the blood vessels varies considerably. The contraction and dilation of the skin vessels make the affected person feel cold and hot and headache may arise due to spasmodic contraction of the vessels in the brain, and when the sweat glands are also stimulated hot or cold sweat appears on the forehead. Even the nerves to the gut may be stimulated and lead to purging.

In short, the nervous stimulation of the centre for equilibrium may spread to any part of the body which is controlled by involuntary nerves. In addition the nerves to the stomach may be directly stimulated by the tugging of the stomach on its suspensory folds. Therefore the forms of seasickness are extraordinarily varied. They vary from slight nausea, slight fatigue, moderate headache, distaste for activity, to uncontrollable vomiting and complete depression of thinking and loss of will power. With this may occur disturbances of the skin circulation of all types, sweating, flow of saliva, purgation, and disturbances of the action of the heart and respiration.

The extent to which the capacity of a flier has been decreased cannot be judged by the amount of vomiting because there are persons who vomit without much sensation of being upset. And, on the contrary, there are persons who have the most marked sensations of sickness and do not vomit. Then there are persons in whom a general bodily and mental depression dominates the expression of air or sea-sickness, and finally all the forms may occur more or less severely together.

The tendency to air sickness differs greatly in different individuals. Most persons adapt themselves quickly to the motion of the aeroplane. Usually it is easier for the pilot to adapt himself than others, because he sits close to the centre of rotation and senses the movement actively because he is flying and not passive like the others. Very few passengers leave the aeroplane after a long flight in rough air with a feeling of entire well being and mentally fresh, especially if they are sitting several metres beyond the centre of rotation, as the movement to and for greatly increases with distance from the axis. Therefore it is advisable from this point of view and others to arrange the places of the crew as close as may be to the centre of rotation of the aeroplane; but it is also wise, if the character of the flight allows it, to seek as far as possible for quiet air levels.

When flying in an enemy country this is usually possible, since on account of the danger from the earth the flight will be carried out at a high level and above 9,800 ft., where the vertical movement of the air, i.e. the squalls, are relatively few even in hot summer days.

If the pilot becomes air sick, the safety of the flight is endangered and sickness of the crew decreases their ability to do their duty. Hence people with a hypersensitive centre for equilibrium, for example those who do not accustom themselves to the ship's motion on a long voyage, are quite unsuitable as flying personnel.

In attempting to combat air sickness we must distinguish between fighting its cause and decreasing its symptoms.

To combat the causes, seek out quiet air strata and avoid flying in bumps; avoid unnecessary manœuvres and undue movement of the aeroplane; provide adequate and intelligent aeration of the cabin, since the smell of oil and exhaust gas increases greatly the tendency to air sickness.

To diminish one's own symptoms we recommend either as comfortable a position as possible, best of all lying down, moving the head as little as possible, looking at the horizon if possible—if not, keeping

the eyes closed; or, on the other hand, trying to ward it off by as intense an employment as possible.

Certainly one must on no account pay attention to the motion but must force oneself to think of something else. If the sickness is severe, only the greatest exertion of the will can accomplish this, as the will power is already weakened.

Finally, there are drugs which may be used for air sickness. Their effect, like air sickness itself, varies much with the individual. The more potent have in addition undesirable additional effects.

The flying personnel of a fighting craft should not take drugs before going up but should learn to adapt themselves as quickly as possible. Pupils in training should indulge in the various amusements of a pleasure resort, like the roller coaster, etc.

G. SPORT FOR FLYING PERSONNEL

The physical capacity of the flier, his resistance to the effects of altitude, to centrifugal force, and to fatigue due to long flying, may be considerably increased by an intelligent use of sport. For this purpose those sports are most advantageous which train the respiration and circulation for enduring activity, such as long distance running, climbing mountains, skiing, swimming, and rowing. Overtraining is, however, very inadvisable and very thorough training for contests may be very unfavourable, since in the height of training the whole organism is hypersensitive as is evident from the fact that the stage of maximum training can only be maintained for a very short time. In general it may be said that the flier should seek his laurels in flying and not in sport.

Overtraining, particularly in track and field sports, reduces the capacity to resist the effects of altitude and centrifugal force, because there is a tendency to a sudden relaxation of the blood vessels which may result in fainting. This increased tendency to fainting is found most markedly in young persons who are still developing, after severe efforts in track sports. In developing any form of training, attention should be directed to seeing that no marked exertion is taken before a flight.

Again, strenuous bodily exertion should not occur before an important period of instruction, because after such bodily exercise the muscles are abundantly supplied with blood at the cost of the flow to the brain and consequently the attentiveness decreases and the inclination to sleep increases.

The practice of boxing and jiu-jitsu is strongly recommended for fliers. Boxing is an excellent exercise for developing respiration and circulation and strengthens the whole body. Both sports develop hardness, strengthen the fighting spirit, and teach like all sports where two are opposed—i.e., fencing—quickness of observation and action. This is supremely true of jiu-jitsu.

Since boxing and jiu-jitsu are also excellent methods of self-defence, they develop a calm self-control when one is insulted.

Tennis is also recommended for fliers. If one is dexterous enough it is an excellent competitive sport, and watching the ball sharpens the estimation of distance of moving objects, so important to the flier.

For fliers in fighter aeroplanes, who usually fight as a team of three, all those games which require team work—football, "handball," and hockey—are good preparation for team work during the attack. They also strengthen the entire body. Football is to be recommended above "handball" because the latter, according to our experience, leads to more accidents than any of the sports save Rugby football, which is not much played by us. This is particularly true if the "handball" team is not very skilful.

The most important sports for all fliers are skiing and climbing in the mountains, for these improve the endurance of altitude both by adaptation and by general bodily development. Even if the adaptation to altitude brought about by an increase in the number of red blood cells which is produced by a long sojourn is not to be observed by an examination of the blood after 1-2 months, nevertheless an improved capacity to resist altitude remains, since provision for supplying adequate oxygen to the tissues during the ascent is available—an increased supply of red cells from the depots, spleen, etc., an increase in respiratory capacity, and an increase in the circulation.

Adaptation to altitude is a gradual and widespread attuning of the body to a sojourn in an oxygen-poor air, which after several weeks at heights above 19,600 ft. may proceed so far in suitable persons that mountain climbing may still be carried out at from 22,900-26,200 ft. quite as well as by the ordinary mountain climber at 9,800 ft. The expeditions to the Himalayas have demonstrated this.

A sojourn of 3-4 weeks continuously at heights of 9,800-13,000 ft. with activities such as climbing and skiing, increases the resistance to the effects of altitude and also the interval of reserve which is so important in the avoidance of death. The danger of failure of the respiration at great heights is definitely decreased because the time between the cessation of breathing of oxygen and the symptoms of severe altitude sickness (interval of reserve) is increased. The increase in resistance may be valued at 3,200 ft. and the time reserve increased threefold.

Hence climbing and skiing in the mountains is an excellent method

of increasing the resistance to altitude and improving the ability to fly high.

Systematic training under medical direction at altitudes of 9,800-13,000 ft., increases the resistance to altitude, probably about 4,900-6,500 ft., so that such a trained man would only have to have recourse to the oxygen supply at 18,000-19,600 ft. If the oxygen apparatus failed at 24,000-26,200 ft., the effect of altitude in these persons would only be equivalent to what would happen in the untrained person at 19,685 ft., and the interval of reserve would be correspondingly improved.

The question of the necessary duration at 10,000-13,000 ft., to produce this improvement has not been sufficiently investigated. Therefore it is definitely forbidden, because of a sojourn in the mountains, to neglect to use the oxygen apparatus above 15,000 ft., as is laid down in the regulations.

It is conceivable that for particular purposes in the future it may be advisable to train persons in the mountains to as high a resistance to altitude as possible and have them carry out a flight during the period of fullest adaptation.

Such adaptation cannot be achieved by high flying because the duration of the flights is too short. The possibility of carrying out adequate activity in an aeroplane is too limited and in addition it would be too costly.

Skiing even at low elevations is a splendid sport for developing the capabilities of fliers, particularly if long periods of office work, as well as flying duty, prevent much sporting activity, and during leave the body has to be got into shape again.

Skiing, whether long distance, climbing up hill, or even during the descent, strengthens the muscles of the whole body. During downhill running the body muscles must contend with the great speed, and in beginners with the constant falling and getting up again. The respiratory organs are at work in cold, dry air which decreases the tendency of the air passages to catarrh; the heart is strengthened and the circulation improved. Further, skiing is a splendid training for developing endurance and courage.

Exercise for the Parachute Landing

As preparatory exercises for parachute landing, to which every flier must entrust himself in an emergency, the following sports are to be recommended—diving, rugby, soccer, apparatus work in the gymnasium, jiu-jitsu, and above all "tumbling." The most important is the "roll" learnt in "tumbling," both forwards and backwards from at rest and when running. It teaches the parachute jumper to break his fall and also to be able to get up again at once, which enables him to avoid being dragged along the ground. Diving, especially from the high board, makes jumping from the plane easier, accustoms the flier to fall freely and teaches him to manage his posture and position in the air.

Rugby, soccer, apparatus gymnastics, and jiu-jitsu teach pliant falling and immediate getting up again and give the parachute jumper the necessary hardness of body and mind.

H. HYGIENE

1. Care of Skin and Mouth

Owing to the close relationship between a flier's general well being and his usefulness, he should look after the care of his skin and particularly of his mouth and teeth.

To harden his skin, swimming is strongly recommended, particularly as this improves his respiration and circulation. The benefits are increased if he can take sun baths of a reasonable character with his swimming.

A marked reddening of the skin by exposure to the sun is to be avoided because this is a sign that the cells of the skin have been damaged and poisonous substances are being carried into the blood stream which increase fatigue and diminish the resistance to altitude and centrifugal force. The resistance of the skin to infection is also decreased and there is more likelihood of skin troubles, boils, and pustules.

Before sun bathing the skin should not be washed free of its normal greasy covering as this protects the skin against the ultraviolet rays which are particularly potent at high altitudes, and also serves to protect against the cold. Consequently the personnel of an open aeroplane should not soap their faces when washing and as far as possible avoid shaving before a flight.

The natural protection against sunburn is tanning, the deposit of a dark pigment in the skin. Blond persons can only acquire such a tan if they are very cautious in the exposure to the sun, and may fail. As a protection to untanned skin against sunburn, a thick covering with a skin salve which contains substances which absorb the ultraviolet rays is recommended.

During high flights in an open machine, the important thing is not the protection of the face against the sun rays, which is accomplished by the helmet, mask, etc., but against cold, to which the use of a salve

greatly contributes. The salve may contain camphor or other substances which will increase the flow of blood to the skin and decrease the chances of its freezing. After a high flight it is a good thing to wash off the face first with cold and then with hot water several times, and it is best to use separate sponges.

Frostbite, which consists in redness, swelling, or the formation of blisters and a tight, pricking or itchy feeling, requires the attention of the physician.

Except in winter, it is unavoidable that the personnel should sweat before the start and after landing in their heavy special clothes. The very marked changes in temperature that they undergo increases any tendency to rheumatic colds. Therefore the sweaty underclothes should be removed as soon as possible after the flight, especially as moist clothes are a poor protection against heat and lead rapidly to chilling due to evaporation. If the clothes cannot be changed, they should not be allowed to dry out when the flier is sitting or standing in a draught, as this leads to rheumatism and catching cold; the wearer must keep moving about.

After a long strenuous flight, a short warm bath or shower, with a cold one following, should be taken. The cold douche, however, should not include the head. A bath prolonged for a half hour is not advisable, save before going to bed. Then the bath has a restful influence and one that helps sleeping if it is not taken too hot. During the day such baths are weakening, but short baths or douches are not to be feared.

In summer, even shortly after a flight, a short cool (but not ice cold) douche can be taken without hesitation. Pale, thin persons with a tendency to headache (rarely found among flying personnel) should be advised not to take cold douches or baths, particularly after warm ones.

Thorough cleansing of the mouth and teeth must be practised by fliers if they are to avoid the early loss of their teeth, since the inhalation of the cold air or the oxygen that becomes cold during its expansion may lead to slight cracks in the teeth, which easily become the site of decay and infection. After exposure of the teeth to cold, as they warm up there may be a difference in expansion between a tooth and its filling, so that a little space is formed which may become infected.

A tooth with an improperly filled canal may become the source of severe pain due to the expansion of any gas within it. The teeth must be brushed morning and evening with a soft brush and care must be taken that through rough brushing the gum is not forced away from the neck of the tooth, but the tooth and gum should be brushed from gum to apex, which massages the gum and keeps it healthy.

Tartar should be removed at once by the dentist and holes should be filled immediately. At least every six months a visit to the dentist should be made.

If an inflammation of the gums occurs, the physician should be notified. This may be due to a diseased tooth or some damage to the gums; but may also be the symptom of general disturbance of nutrition, a vitamin lack or, in the ground personnel, of lead poisoning due to careless handling of a lead solder. Such inflammation of the gums should be treated at once and thoroughly, either locally or indirectly as the case requires.

For the care of the mouth only the mildest means should be used. If hydrogen peroxide is used, it should be diluted, one small teaspoonful to a glass of water. After a long high flight gargling with chamomile tea is good for a rough throat and helps in preventing inflammation.

2. Food, Sleep, and the Use of Alcohol

The food provided for the flying personnel should be good but easily digestible. Voluminous foods or those which, like beans, tend to the formation of gas, should be avoided before flights at high altitudes, 22,000 ft., as the distension of gas in the intestine might be serious. On the other hand, food taken before a flight should have a staying quality; it should not leave the stomach too fast so that soon after his meal the flier has an empty feeling, as this leads to a decrease in resistance to altitude and especially to centrifugal force. It is hence advisable in the case of longer flights to have something to eat with one; unsweetened chocolate is particularly suitable as it contains substances which, like those in tea and coffee, are stimulants to the brain (owing to increasing its blood supply).

In no case should a flight be made in the morning without food, as this reduces the flier's resistance greatly and may even in healthy and powerful persons lead to fainting under the stress of flying. This is particularly true in the case of a flier who has had a sleepless night.

A lack of vitamin C must be avoided by eating adequate amounts of vegetables, salads, raw fruit, or fruit juices, as otherwise an obstinate inflammation of the gums with loose teeth may occur.

The food should be of a wide variety so that all the necessary vitamins may be obtained. The importance of the vitamins for the maintenance of health has been abundantly shown by scientific experiments in the last ten years.

Meals should, as far as possible, be taken at regular hours; in the morning a light digestible breakfast, but if hard flying is expected it should be more abundant.

If the start is to be made some time after breakfast, a second meal should be taken before flying. (The feeling of hunger should not in this case be assuaged with a cigarette.)

The midday meal between 12 and 13 hours should be the chief warm meal of the day, but if the start is to be made just afterwards, should be smaller than usual.

The evening meal should be taken at least an hour before going to bed, as otherwise the digestion suffers.

Care should be taken that stools are passed regularly, as constipation leads to headache and a decrease in flying capacity and usually to the accumulation of gas which is unfavourable.

Diarrhoea naturally makes one quite unfit for flying duty.

Most digestive disturbances are readily alleviated by medical treatment and advice, if treated in time, but if not, may prove very resistant. If constipated the flier should consult the physician.

A tired man cannot accomplish much. Sufficient, but not excessive, sleep is a fundamental condition for bodily and mental exertion. That of course goes without saying, yet must be said from time to time to the flier lest, as experience has shown, his social inclinations lead him to waste too many merry hours with his friends and comrades.

Taking of moderate amounts of alcohol in the form of beer or wine in fresh air is not harmful for a morning's flight if the flier has had at least 6-8 hours of restful sleep in between. But an evening with alcohol which lasts into the morning hours is not compatible with doing full duty on the next (same) day. The preaching of complete abstinence is to be avoided, as it leads to hypocrisy and a feeling of restraint. On the other hand, care should be taken that any flier who does not wish to take alcohol should not have pressure brought on him to take it.

Taken as a whole, a moderate use of alcohol aids in the development of comradeship in our Nordic, somewhat reserved men and aids in their getting together and in diminishing any strangeness amongst members of the mess. But a superior officer should exercise his tact to see that an evening does not lead to the contrary.

A true sense of comradeship cannot be forced by festive evenings with alcohol. And great care must be taken in the selection of personnel to see that the men who come together as men become comrades naturally as a result of their education and upbringing.

The use of alcohol directly before a flight is to be forbidden a flier just as sharply as it would be to a motor truck driver.

I. THE IMPORTANT POINTS IN THE MEDICAL EXAMINATION OF FLYING PERSONNEL

The piloting of the ordinary sport aeroplane with a low landing speed is not a "black art" and can be learnt by any man of normal intelligence and sound sense organs. But flying a high powered aeroplane requires the ability to serve and watch over a highly developed machine and demands a high degree of skill and ability on account of the long runway and the speed of landing.

We today only consider a pilot as completely trained when he is able to carry out his flying orders in any weather and at night. Pilots must therefore have at least certificate B for blind flying, which qualifies them to proceed for certificate C, which allows them to fly blind take offs and landings with a multi-engined aeroplane. With good fundamentals this education can be obtained in 1½ years of intensive schooling.

It no longer suffices that the pilot has learnt to fly a plane well and can start and land without error. This can be learnt by even the less gifted. He must in addition have the ability to think out quickly and successfully the difficulties he encounters in flight, which requires high mental ability, particularly in blind flying.

During a high flight he must watch over his oxygen apparatus and also keep an eye on the crew, so that by descending quickly to a lower level he can save from death any member of the crew who has become unconscious from oxygen lack. In short, the pilot is to be no longer regarded as a mere helmsman of a ship but as the responsible captain and first engineer, entrusted with a 1000 horsepower machine. He must be a person with highly developed intelligence, with the power of rapid clear decision, and a high sense of responsibility, who can keep his "nerve" in difficult situations and after long-lasting strain, and a person with a high soldierly character.

In addition, the strains of flying require a thoroughly sound body and sound sense organs if he is to do his military and flying duty as a pilot.

Therefore we pass into the flying service, either military or civil, only persons who have been found by thorough examination to be sound in body, mind, and spirit and whose mental make-up appears likely to enable them to be trained at least as far as the C certificate, who have the character to become disciplined combative fliers, the ability to stand firm in difficult situations, and the poise to be good comrades.

The medical examination for fitness for flying may be compared to the general inspection of a flying machine.

First, the applicant's general life history is obtained. His medical history and that of his family is carefully ascertained to discover whether there is a possibility of any inherited disability or any predisposition to disease, and naturally whether he shows any definite deficiencies in his health. This is followed by a thorough investigation of all his organs. It is ascertained whether his vision (without glasses) is adequate, whether he possesses full colour vision. In this test he must be prompt in his recognition of the coloured lights. The balance of his external eye muscles must be perfect, since otherwise his appreciation of depths (stereoscopic vision) and his appreciation of speed during landing will prove deficient. His hearing is thoroughly tested and also tests are made to show whether he has any hypersensitivity of his organ for equilibrium in the internal ear and whether his passage for the maintenance of pressure equality between the middle ear and the atmosphere is clear, and whether there are any changes due to disease in the nasopharynx.

Tests are applied to show whether his respiratory and circulatory organs are sound and their capacity is tested. If a low pressure chamber is available or an apparatus for giving low percentages of oxygen, then tests with them should be applied in order to judge of the applicant's fitness to withstand altitude and of his reactions to oxygen lack, though these may vary greatly even among those considered fit for military flying. This test is also of a great practical advantage to the man examined as he learns whether he is able to observe the onset of symptoms and what form they take, whether altitude sickness appears suddenly or gradually, and whether he stands the oxygen lack well or just passably. It may also be possible to ascertain his interval of reserve after cutting off his oxygen supply at low oxygen pressures. It is also important for those who are allotting his duties in the air to know the physician's estimate of the qualifications of the candidate.

For the final estimate of flying fitness, the examination by the neurologist is particularly important. It must be known whether the nervous system and the whole expression of the candidate's personality which is bound up with it, appear likely to withstand the stresses, so that we may avoid the labour and costs of training persons who can learn to fly safely and well and yet on account of their mental make-up fail at later stages because their nervous system and personality give way owing to the strain of blind flying or the stress thrown upon them by other conditions.

Intelligent persons who lack endurance in spirit and in their nervous system are found to be deficient only very late in their training. Some of these can be detected by the experienced examiner, particularly since lack of endurance in spirit and in nerve is often caused by heredity and natural disposition and is accompanied by physical characteristics.

A thorough medical examination for flying fitness should be made every year and after severe sickness or accidents. These examinations may be carried out by the squadron medical officer, if he has had adequate medical and flying experience. Otherwise the examination must be carried out by a superior officer with the necessary technical training.

Every five years a special general overhaul by such specialists should be given.

The chief reasons for the yearly medical examination are:

1. The maintenance of flying fitness by the early recognition of slight disturbances of health, which can be removed by medical treatment.
2. The removal, temporarily or permanently, from the flying list of those persons whose physical condition is such as to make them a danger to themselves or others.

The foundation for such re-examinations should be laid by the constant medical observation of the flying personnel by the squadron physician. It forms also the foundation of the constant medical care which is discussed in the next section.

J. THE FLIER AND HIS MEDICAL OFFICER

The foregoing discussions and explanations have made it clear that the modern high-powered aeroplane can only be used to its full capacity by its crew if the assistance and advice which have been suggested as a result of the medical investigations into flying are accepted by the flying personnel.

Even more important than the co-operation between medical investigation and technical development is the proper trustful relationship between the squadron medical officer and each flier if his fitness is to be maintained or increased, so that the fullest use can be made of the air arm.

The medical officer may be regarded as the "technical" officer in charge of the efficiency of the personnel. He has to care for the maintenance of the flying fitness of fliers. The material with which he must deal is living men, indivisible and individual combinations of bodies and minds. Therefore the physician to the air force must in his care of the personnel endeavour to attune not only their bodies but their spirits to the tasks before them.

This recognition of his dual task is particularly important in regard

to those who are actually flying, because a bodily illness not only decreases the individual's resistance to the physical stresses imposed by flying, but also to those that are mental and of the spirit. Any decrease in these qualities will also prevent the flier withstanding as he should the mental strain of the hazards encountered in war. On the other hand, if a flier's spirit and his nervous system becomes unstable owing to frequent accidents or the excessive mental strains of repeated dangers, these may affect his bodily well being and produce the state termed "flown out," or the "flier's sickness" of the French, which presents the symptoms of a nervous exhaustion (loss of appetite, paleness, pounding heart, a feeling of anxiety, etc.).

The statistical analysis of accidents, both at home and foreign, shows clearly that most accidents are due to a failure of morale at a critical time, and this depends on the state of the nervous system of the individual. The fundamental cause of false decisions at a critical point during flying is only rarely the lack of technical knowledge, but usually is due to over-hasty decisions due to an internal unrest and anxiety—that is, it has a nervous basis.

In war it is the fighting spirit of the crew which is the decisive factor in carrying out the duties assigned to them successfully, and a failure of spirit under the constant strains upon the "nerves" is the most frequent cause, except the action of the enemy, of failure to perform the duty assigned.

Also behind a great number of the accidents during foolish "stunting" at low levels (perhaps with relatives or a bride aboard) is found a mental lack of self-confidence. The fliers must show off to prove to others that they are great fellows. The difference between what they wish to appear to themselves and what they can really do often leads to a catastrophe. And it is well known to many of the careful medical examiners that there are persons with a poor hereditary background who strive to become fliers just in order to increase their self-esteem by showing others their great manliness.

[The following example of this type of inner uncertainty may serve as an illustration. A young observer started his plane in spite of orders forbidding it on account of fog. The crash occurred shortly after the start when he was trying to return to the flying field. The most probable psychological reason for this forbidden and suicidal flight was the half-conscious desire to appear to himself as a conqueror, which was out-bid by a hasty decision, a lack of mental certainty. Perhaps a close comprehending understanding between the squadron leader and the physician might have led them to recognize a tendency in this young flier to make rash decisions due to an uncertainty of character, and might have resulted in its eradication.]

The well-known proverb, "prevention is better than cure," has a quite peculiar importance in the medical guidance of flying personnel because in this service a human failure so frequently makes cure impossible by death.

Successful prevention in the sense of the avoidance of accidents and injuries incurred in flying duty is only possible if there is the closest understanding between the physician and the squadron leader, and this requires as foundation that the physician has the full confidence of, and is trusted by, each of the fliers.

This foundation for the medical guidance of the fliers has not yet been laid everywhere, although its value for the decrease of flying accidents has been proved by flying statistics throughout the world since the last war. The reasons why it has not been established are various. Partly it is due to the fact that the medical officer is not a qualified pilot and is not even able, as an "observer" would be, to judge properly the bodily and mental exertions of flying personnel. Also as yet, owing to a shortage of medical officers, only some of them have been put through the courses which enable them to understand the important physical and physiological problems of high flying. Those who are now entering are fortunate in having had a proper training.

This lack of proper instruction, which is now being filled, together with the general deficiency of the young physician in experience of life, has frequently led to his neglecting the particularly important duty of watching over the flying efficiency of the personnel under his care by thinking about their mental and nervous state. This is particularly true since during his university training the study of psychology and of the character of persons has usually been very largely neglected. And because of this lack it is easily understood that for the judgment of character, non-medically trained psychologists have had to be drawn upon. It is, however, clear that owing to the close relationship between bodily and mental states, a physician trained in psychology and in aviation medicine should have a marked superiority to the psychologist.

If the physician attached to the flying service has not been properly trained for his duties in the air force and has not acquired a knowledge of his particular duty, he is apt to underestimate this most important side of his medical work. And such a physician will soon find that his work is confined merely to the care of the sick, general sanitary problems, and preparation for the care of accidents. These are the duties of a medical officer with the army and must, of course, not be neglected, but owing to the peculiar conditions arising through flying must be enlarged as shown above.

Therefore, the squadron leader should, in the interest of his squadron, make a continuous effort to see that by guidance and advice he makes the medical officer fully conscious of this duty.

The physician must endeavour to form his personal judgment in regard to each of the pilots and of all of those in the crews. Flying as an observer, in flights with definite objectives in bad weather and at high altitudes, makes this judgment both easier and firmer and acquaints the physician with the bodily and mental exertions that the flying service requires of its members.

The observation of starts and landings, with the squadron leader or instructor or an experienced flier, will deepen his knowledge of the varying peculiarities of the different pilots. Observation of difficult landings in small fields, as during practice in the country, is very instructive in forming his opinions.

Discussion between the leader and the physician in regard to changes in the flying behaviour of individual fliers, or changes in their general behaviour and attitude to their routine and extraordinary duties, is very important.

Through such discussions also the inexperienced medical officer will learn to recognize the early indications of nervousness and being "flown out," and will soon learn to realize when a pilot is trying to cover up his feeling of insecurity by exaggerated efforts and has become a danger to himself and his crew.

Regular physical examinations with their accompanying questionings of the personnel are a very great aid in watching over the changes in personality. Lectures given by the medical officer on the subject of the physiology of flying (aviation medicine) are of value, as are discussions with individual fliers on the proper feeling of confidence that should exist between the flier and the physician. Further, the physician in his social relationship with the members of his squadron should develop the mutual feeling of comradeship. The fact that the routine examination for fitness is entrusted to the squadron physician should increase the close relationship between physician and flier.

The airman should not hesitate to reveal to the physician any symptoms of ill-health and should obtain his advice, as it is often possible to treat and cure these without the interruption of flying service, while if the symptoms are neglected it may lead to a long period of treatment and interruption of duty.

The airman should seek advice in regard to the observations he makes on himself during flying, the effect of height and centrifugal force. He should also report the presence of increased amounts of exhaust gas.

The airman should have the feeling that he can and should go to the physician with all the worries which arise in his duties as the latter is responsible for watching over not only his bodily but mental health and any other factor that will decrease his personal efficiency.

It is consequently worth while for the physician to set aside regular hours at which he may be consulted.

The airman must learn to regard the physician as his friend who will help him to maintain his efficiency and aid him in carrying out his flying duty and will strive to protect him from the dangers and defeats that will arise from it.

We should not wait till the young airman, full of confidence in himself and in his health, is forced by the piling up of avoidable minor accidents to realize that the limit of strain that is compatible with health has been reached in our modern high-power aeroplanes and compels him to recognize that the experienced physician, who is learned in aviation medicine, can aid him to avoid overstepping the limits of his resistance.